THE UNIVERSITY OF ALBERTA

SEDIMENTOLOGY AND VEGETAL MICROPALEONTOLOGY OF THE ROCKS ASSOCIATED WITH THE CRETACEOUS KNEEHILLS TUFF OF ALBERTA

by

© PIER LUIGI BINDA, Doctor of Geol. Sci. (Univ. of Pavia, Italy)

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA

SPRING, 1970

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Sedimentology and Vegetal Micropaleontology of the Rocks Associated with the Cretaceous Kneehills Tuff of Alberta", submitted by Pier Luigi Binda, in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

"When nature is on the point of creating stones it produces a kind of sticky paste, which as it dries, forms itself into a solid mass together with whatever it has enclosed there, which, however, it does not change into stone but preserves within itself in the form in which it has found them. This is why leaves are found whole within the rocks which are formed at the bases of the mountains, together with a mixture of different kinds of things, just as they have been left there by the floods from the rivers which have occurred in the autumn seasons; and there the mud caused by the successive inundations has covered them over, and then this mud grows into one mass together with the aforesaid paste, and becomes changed into successive layers of stone which correspond with the layers of the mud."

LEONARDO DA VINCI

(English translation by E. MacCurdy)

ABSTRACT

Claystone and tuff samples from the Battle Formation, the Battle Member of the Edmonton Formation ("Kneehills Tuff horizon", "Mauve shale", "Blackmud"), and subjacent sandstones and claystones ("White Sandstone" and Whitemud Formation), collected from 27 localities in the Alberta Plains and the Cypress Hills, were subjected to environmental analysis.

Grain-size analyses of 73 samples from sandstones underlying the Battle Member in southern Alberta indicate the presence of a fluviatile environment immediately prior to the deposition of the dark shale of the Battle. Various sub-environments found in present-day rivers are detected from the comparison of the grain-size distributions of these sandstones with those of recent sediments.

Size analysis of the coarsest fraction of the Kneehills Tuff confirms a southern source for the ash.

X-ray analysis of clays from 36 samples of claystones and sandstones show a montmorillonite-kaolinite assemblage, also suggestive of fresh-water conditions.

Isotopic analyses of siderites from the Whitemud Formation yield δO^{18} values that are typical for carbonates formed in fresh water. The δC^{13} values obtained, although identical to those of marine siderites, also occur in siderites from part of the Edmonton Formation that are certainly continental.

One hundred and thirty-five samples from the Battle Member and Battle Formation and 70 from the underlying sediments reveal

the presence of the megaspores genera: Triletes, Minerisporites, Warrenisporites, Erlansonisporites, Henrisporites, Verrutriletes, Horstisporites, Stelckisporites, Selenasporites, Balmeisporites, and Azolla; and of the "seed" cuticles genera Spermatites, Costatheca, and Carpotheca. Forty-three species belonging to the above 14 genera are described and illustrated; all megaspores from the Battle are silicified.

All the microfossil remains in the Battle and in the underlying sediments belong to plants that are indigenous to the continental environment; no marine fossils were found. The dark shale of the Battle is considered to have been deposited in a swampy or lacustrine environment accompanied by a considerable fall-out of volcanic ash.

The correlation of the Battle Member of the Edmonton Formation (Alberta Plains) with the Battle Formation (Cypress Hills) is indicated by both micropaleontological and lithological evidence.

ACKNOWLEDGMENTS

This thesis was prepared under the supervision of Professor C.R. Stelck and Professor J.F. Lerbekmo. Their guidance in all phases of this work is gratefully acknowledged.

This project involved widely different methods of investigation, therefore the assistance of experts from various fields is acknowledged here, but they are in no way to be held responsible for the conclusions that have been reached.

The help of Dr. Tj. H. Van Andel and his laboratory staff of the Scripps Institution of Oceanography is acknowledged for the grain-size analyses. Thanks are extended to Mr. A.M. Green of Roan Selection Trust for his help in the application of the Factor Analysis to the grain-size distributions, to Dr. P. Fritz for the isotope analyses of the siderites, and to Dr. S.K. Srivastava for important contributions to the micropaleontological section. Advice in this latter field was also received from Dr. C. Singh and Dr. J.D. Campbell of the Research Council of Alberta, Dr. L.V. Hills of the University of Calgary, and Professor W.N. Stewart of the Botany Department, University of Alberta.

Considerable help in collecting samples in the field was provided by Dr. J.H. Wall, Mr. M.A. Carrigy, of the Research Council of Alberta, and by Mr. L.R. Campbell, field assistant.

I also wish to thank Mr. M.H. Dawes and Mr. F. Dimitrov for the drafting, Dr. S.A. Weisberg for help with the photographs, and Mr. M.R. Baaske who skillfully prepared the petrologic thin sections.

My gratitude is also extended to Dr. F. Mendelsohn and Dr. W.A. Hodgson of Roan Selection Trust for critically reading parts of the manuscript.

Financial assistance was provided by the Department of Geology in the form of Teaching Assistantships, by the University of Alberta as a Dissertation Fellowship, and by the Research Council of Alberta which financed the field work.

Finally, I owe special thanks to my wife Sheila, not only for typing all the drafts of the thesis, but also for the material and moral support that she gave me throughout these years of work.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER ONE - INTRODUCTION

THESIS PROBLEM AND ITS HISTORICAL ASPECTS

This thesis is primarily a study of the depositional environment of a white sandstone-dark shale succession at the top of the Middle member of the Upper Cretaceous Edmonton Formation in southern Alberta. The dark shale and a thin volcanic tuff within it are remarkably continuous over a large area. This continuity suggests deposition in an extensive body of quiet water. The main question that this thesis attempts to answer is whether the white sandstone-dark shale succession was deposited in a marine or in a continental environment.

The Edmonton Formation which covers a major part of Alberta east of the Foothills and south of latitude 56°N, consists, in the Alberta Plains, of 1000 to 1200 feet of sedimentary rocks, largely sandstones, siltstones, claystones, and coal seams. Paleontological work carried out by various authors indicates that this stratigraphic unit is Late Cretaceous in age and suggests a predominantly fresh-water depositional environment, with some marine and brackish elements appearing within one particular interval, the "Drumheller marine tongue".

The name "Edmonton beds" was first used by Selwyn (1874) to indicate strata containing coal seams outcropping in the vicinity of what was then Fort Edmonton. The designation "Edmonton Series" was subsequently introduced by Tyrrell (1886). It was not until 1945, however, that a detailed and comprehensive study of the Edmonton Formation appeared in the geological literature. Sanderson (in Allan and Sanderson, 1945) subdivided the formation into three members:

Lower, Middle, and Upper (Fig. 1). The Middle member, approximately 300 feet thick in exposures along the Red Deer River from near Ardley to Drumheller, overlies the "marine tongue" and, according to Sanderson (ibid.), consists of the following units from top to bottom:

Kneehills Tuff horizon

White sandstone

Thompson seam

Grey sands and shales

Carbon seam

Dull grey sandstone

Of the above listed units the most remarkable one is undoubtedly the Kneehills Tuff horizon, a dark bentonitic shale up to 30 feet thick containing a one-foot thick hard, siliceous bed named by Sanderson (ibid.) the "Kneehills Tuff". This dark shale and the enclosed tuff bed have been the object of interest of several authors. Its continuity over a large area and its very diagnostic low resistivity in electric logs have made this shaly horizon an excellent stratigraphic marker used by oil geologists for subsurface correlation. The correlation of the dark shale with an analogous type of deposit, the Battle Formation of the Cypress Hills, was already suggested by Sanderson (ibid.) on the basis of the lithological characters, and has been accepted by Ower (1960) (Fig. 2)* and Elliott (1960) who paid particular attention to the sediments associated with the Kneehills Tuff in their studies of the Edmonton Formation in both outcrops and in the subsurface. Petrographic work on the Kneehills Tuff horizon and on the Kneehills Tuff proper has been carried out respectively by Byrne (1951) and

---

*This thesis.

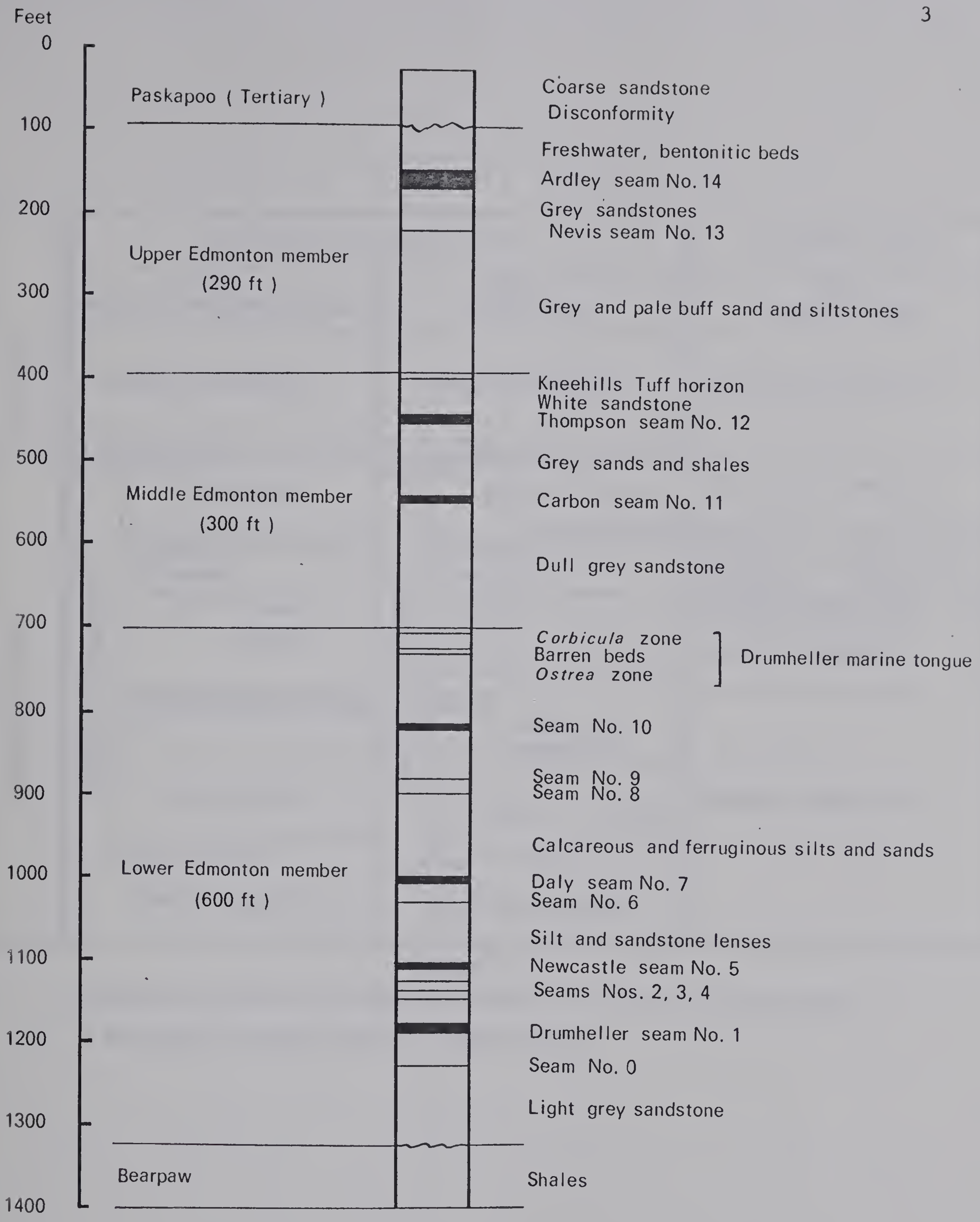


FIGURE 1

Composite section showing subdivisions of the Edmonton Formation.

(redrawn from Allan and Sanderson, 1945)

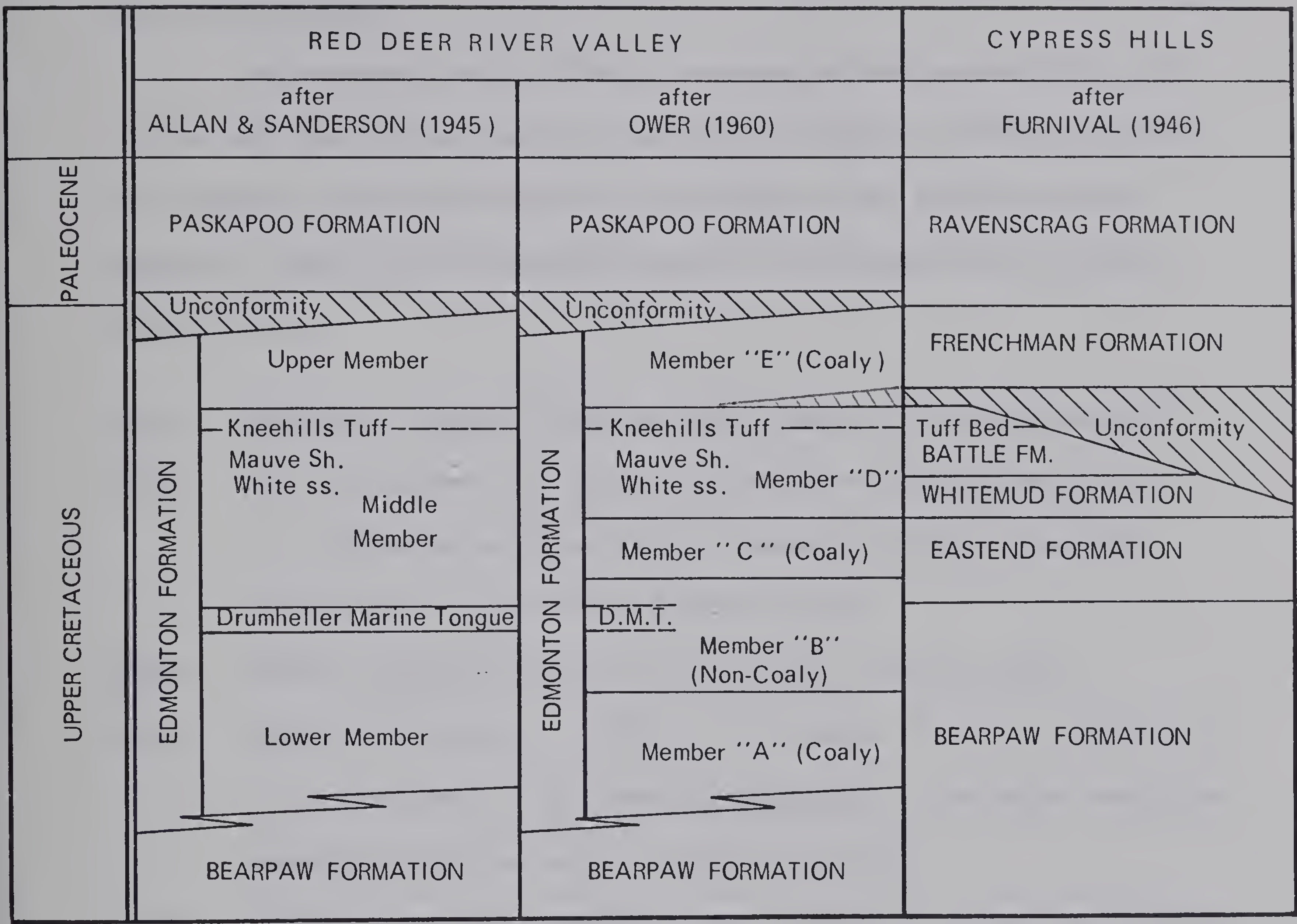


FIGURE 2

Stratigraphic correlation of the Edmonton Formation with the Upper Cretaceous strata of the Cypress Hills area (after J.D. Campbell, 1962).

Ritchie (1957). Absolute age determinations of bentonites of the same horizon have been given by Folinsbee *et al.* (1961) and by Shafiqullah (1963).

The apparent lack of fossil remains and the unusual characters of the unit have given rise to a variety of views by different authors with regard to the depositional environment of the Kneehills Tuff horizon. Some of the prevailing opinions are listed here in chronological order:

1945: Sanderson suggested that the dark shale is "possibly marine".

1951: Byrne considered the Battle Formation of the Cypress Hills to be a "fresh-water deposit" and assumed the same to be true for the dark shale of the Alberta Plains.

1960: Elliott treated the unit as "bentonitic marine shale".

1962: Campbell (footnote, p. 310), on the basis of reported findings of foraminifera of the genus *Globigerina* in the white sandstone, suggested that the unit is marine in origin.

1965: Crockford and Clow suggested that the Battle Formation is marine in origin because it occurs over a very large area and because some foraminifera were reported by T.P. Chamney in the formation, at Battle Creek, Saskatchewan.

1965: Srivastava in a palynological study of some mammal-bearing beds of the Edmonton Formation concluded that the deposition of the dark shale could be explained either by "laking" or by a marine transgression.

1967: Russell and Chamney reported:

"Haplophragmoides sp. occurs in the dark shale, and species of Gümbelina and Haplophragmoides are present in a correlative unit (Battle Formation) in the Cypress Hills of southeastern Saskatchewan". It must be noted that the microfossils in question were not illustrated in the paper and no reference to previous publications was given. In the same study the kaolinitic sandstones underlying the dark shale were interpreted as beach deposits.

1968: Binda and Srivastava, in a preliminary paper on the results of the present investigation, described nine species of silicified megaspores from the dark shale of the Edmonton Formation and from the Battle Formation of the Cypress Hills. The affinity of these silicified microfossils with megaspores of extant ferns living in lacustrine environment was pointed out by the authors.

1968: Irish (in Irish and Havard, 1968) gave a list of microfossils identified by T.P. Chamney in 25 samples of the same stratigraphic units. Silicified megaspores were reported to be present in nearly all samples examined. Other microfossils listed are "Ostracod? (shell fragments)" and "only one poorly preserved" specimen of "?Haplophragmoides sp.". No other marine fossils were mentioned in this paper. The microfossils of the Battle were considered by Irish (ibid., p. 29) as "probably carried by wind to the site of deposition".

1968: Srivastava (1968a), in a comprehensive pollen study of the Edmonton Formation, concluded that the Battle Member (Blackmud), and the underlying sediments were deposited in a continental environment.

1969: Byers, on the basis of a petrologic study and on the strength of the evidence presented by previous authors, treated the Whitemud Formation of the Cypress Hills as fluviatile in origin, deposited in river channels and flood plains. With regard to the Battle Formation, the aforementioned interpretation of a marine origin (Crockford and Clow, 1965) was accepted by Byers.

The sediments associated with the Kneehills Tuff not only make an excellent stratigraphic marker and have wide areal extension, but an important break in continuity in the dinosaur fauna (Sternberg, 1947) and in the microflora (Srivastava, 1965 and 1967) occurs across this interval from the Middle to Upper Edmonton divisions.

The micropaleontological investigation carried out in the course of the present work revealed the presence of vegetal microfossils in both dark and white zones, but no faunal remains were found.

SCOPE OF THIS PROJECT

The sediments associated with the Kneehills Tuff had been dealt with by several authors but the factual information was too scanty to allow more than an educated guess at the environment of deposition. The correlation of the Alberta section with the Cypress Hills-Saskatchewan equivalents was based purely on lithological characteristics. Also, a

very important part of the biologic history of the geological column was completely missing. The fact that absolute age determinations are available for the considered interval, would have enhanced the importance of any fossils that could be found.

It was with these considerations in mind that the present project was initiated. A better interpretation of this portion of the Edmonton Formation could be obtained through a combination of petrographic, textural, chemical and micropaleontological investigations. Although the paleoenvironmental and stratigraphic purposes were the prime concern, the usefulness of certain parameters for the solution of the problems involved was also investigated.

METHODS OF INVESTIGATION

The following phases of investigation were carried out:

1. Measurement and sampling of sections at several localities in the province of Alberta and in a few places in southwestern Saskatchewan.
2. Petrographic study of samples of sandstones, siltstones, claystones and volcanic tuff by means of thin sections, coarse residues, X-ray and thermo-differential analyses of the clay fractions, and a cursory examination of the heavy minerals of a few samples of sandstones.
3. Grain-size analyses of the sandstones and of the coarse quartz fraction of the Kneehills Tuff bed.

4. Isotopic composition of some siderite concretions and spherulites embedded in clays and sandstones.

5. Detailed micropaleontological examination of samples, mostly of claystones.

Since the palynology of the Edmonton Formation has been dealt with in Master and Doctoral theses by S.K. Srivastava (1965 and 1968a), the present work does not deal with pollen, microspores and microplankton, but rather with the larger-size vegetal microfossils, viz. megaspores and cuticles. Some palynological slides from the units under study have, however, been examined on occasion.

STRATIGRAPHIC TERMINOLOGY USED BY PREVIOUS AUTHORS

The lithologic units that form the object of the present study (at least the ones from the Alberta Plains) have been referred to in the literature under various names. In order to avoid some of the confusion that would inevitably be created in the mind of the reader, the most common terms and expressions that have been used are explained below:

Sanderson (in Allan and Sanderson, 1945) named Kneehills Tuff horizon the dark shale that contains the hard grey bed of tuff (Fig. 1). The underlying white bentonitic sandstones overlying the Thompson coal seam are grouped under the name White sandstone.

Byrne (1951) did not assign any formal name to the stratigraphic units. He used terms such as Dark Zone, Kneehills Tuff horizon and White Zone. It has to be noted that his figured section, located "thirty miles southwest of Edmonton", presumably at Strawberry Creek, near the town of

Telfordville, is probably one of the most unsuitable sections to study, due to extensive slumping and to the fact that the base of the White Zone is not exposed. His usage of the term Kneehills Tuff horizon contrasts with the original one, since his term defines an 8-foot interval containing three tuff beds overlain by bentonites and interbedded with shale. Such interval is situated in the upper portion of the Dark Zone.

Ower (1960) in his five-member division of the Edmonton Formation (Fig. 2) introduced the term Kneehills Tuff zone (Member D) and defined it (at least in the Red Deer River area) as: "Black to brown bentonitic shale, containing purplish tuffaceous shale and thin tuff bands near top; often white clay shale and bentonitic clayey white sand at base. Thickness 20-50 feet".

In Campbell (1962) the name Kneehills Tuff Member (interval comprising Mauve shale and White sandstone) is used in the text, whereas Ower's (op. cit.) term Kneehills Tuff zone is used in the illustrations with the same meaning.

Srivastava (1965) used the terms Blackmud (dark shale including the Kneehills Tuff) and Whitemud (white, bentonitic shaly sandstones underlying the dark shale). The Whitemud in the Scollard area would be separated from the underlying coal seam by some "interlensing bentonitic sandstones and siltstones of drab color."

While a wide variety of terms has been used for the same stratigraphic units of the Edmonton Formation, and at times the same names used with slightly different meanings, the Cypress Hills-Saskatchewan counterparts of such units have been more consistently

referred to. The terms _Battle Formation_ introduced by Furnival (1946) to designate the dark shale that includes a tuff bed in its westernmost outcrops, and _Whitemud Formation_ introduced by Davis (1918) to designate the underlying light colored shales, siltstones and sandstones, have been widely accepted and consistently used by a number of authors.

Tozer (1953) used the expressions _Battle equivalent_ and _Whitemud equivalent_ to designate respectively the dark claystone and the white bentonitic sandstone of the Middle Edmonton Formation.

Recently Irish (in Irish and Havard, 1968) treated the dark shale and the white sandstone of the Edmonton Formation as Battle Formation and Whitemud Formation respectively, thus implying original continuity of deposition from the Alberta Plains to the Cypress Hills across the Sweetgrass Arch. The latter two formations were then informally referred to as the "Kneehills Tuff zone". To give formation status to these two units, the Edmonton Formation had to be raised to the rank of Edmonton Group. This practice can perhaps be justified for the Battle, in spite of the large gap separating the southeasternmost occurrence in the Plains from the outcrops in the Cypress Hills. It is not advisable, however, to use the Cypress Hills term Whitemud Formation for the white sandstone of the Alberta Plains, since a direct lithologic correlation is impossible.

STRATIGRAPHIC TERMINOLOGY USED IN THE PRESENT STUDY

In the present study the relationships between the Kneehills Tuff horizon (_sensu_ Sanderson) and the Battle Formation of the Cypress Hills have been investigated. The results of the study allow us to consider

the two units as time equivalents as well as lithologically identical. They are, moreover, characterized by the presence of the Kneehills Tuff bed, and they are homotaxial. Therefore, for sake of clarity and in order to avoid the confusion created by a riddle of names all hinging around the basic term Kneehills Tuff, the Kneehills Tuff horizon (*sensu* Sanderson) is here referred to as the *Battle Member of the Edmonton Formation*, or simply *Battle Member*. When the name *Battle* will be used without any other designation, it will indicate both Battle Member and Battle Formation considered as a continuous unit. The name *Kneehills Tuff bed* will be retained to designate the hard, siliceous grey layer occurring toward the top of the Battle. The light colored claystones, siltstones and sandstones underlying the Battle Member will not be given a formal designation, but will either be referred to as "White Sandstone" or, more generally, as "sandstones of the Middle member of the Edmonton Formation".

CHAPTER TWO - FIELD DESCRIPTION

LOCATIONS AND SAMPLING

All the material examined was collected by the author from outcrops in Alberta and southwestern Saskatchewan, with the exception of samples from one subsurface drill-core near Wizard Lake (WL) obtained through the courtesy of the Research Council of Alberta. Localities are given in Figure 3 and Table I.

The best outcrops of the Battle Member and underlying sediments occur in the Red Deer River Valley from south of Alix to Morrin Bridge, in Horseshoe Canyon (near Drumheller), in the Wintering Hills and around Gleichen. Outcrops near Edmonton (Strawberry Creek) and in the Hand Hills were also examined and sampled but due to slumping, vegetal cover, or weathering, they were not found suitable for study. Outcrops of the Battle and Whitemud Formations are abundant in the Cypress Hills of Alberta and Saskatchewan since the Whitemud is quarried for industrial purposes. Most localities are easily accessible by car, but a motor boat was also used for examining and sampling sections on the banks of the Red Deer River.

Sections were measured by means of a meter stick and a Brunton compass. The metric system was adopted. As a general rule, samples were taken at every noticeable lithologic variation in the units under study. When the lithology appeared to be uniform in megascopic view, samples were taken at stratigraphic intervals of one meter.

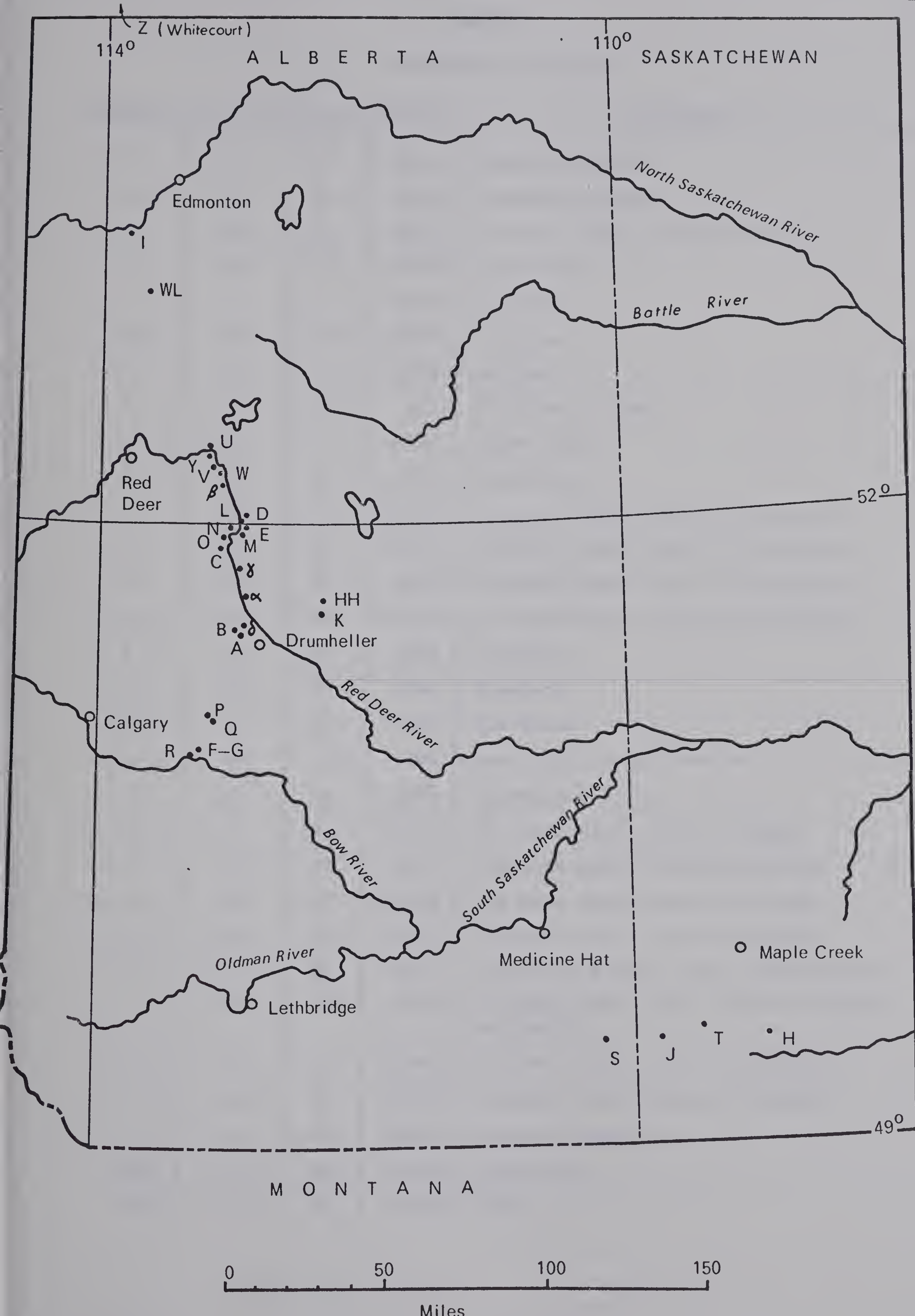


FIGURE 3

Map of southern Alberta and southwestern Saskatchewan showing sample localities.

TABLE I

Sampling Localities

Samples	Section	Twnp.	Range	Locality
A	27	28	21W4	Horseshoe Canyon
B	34	28	21W4	Horseshoe Canyon
C	28	33	22W4	Red Deer River, Tolman Bridge
D	16	35	20W4	Big Valley
E	15	34	21W4	Scollard
F-G	13	22	23W4	Gleichen
H	6	7	21W3	Eastend
I	5	50	2W5	Strawberry Creek
J	32	7	28W3	Adams Creek
K	2	30	17W4	Hand Hills
L	23	34	21W4	Red Deer River, west of Scollard
M	18	34	21W4	Red Deer River, west of Scollard
N	33	34	21W4	Red Deer River, west of Scollard
O	8	34	22W4	Red Deer River, west of Scollard
P	30	24	22W4	Standard
Q	28	24	22W4	Standard
R	8	21	23W4	Bow River
S	9	8	4W4	Quarry 45, near Elkwater
T	27	6	23W3	Ravenscrag Butte
U	5	39	22W4	Red Deer River, Nevis Bridge
V	3	38	22W4	Red Deer River, east of Ardley
W	26	37	22W4	Red Deer River, east of Ardley
Y	34	38	23W4	Red Deer River, east of Ardley
Z	6	60	12W5	Athabasca River, west of Whitecourt
α	32	30	21W4	Red Deer River area, between Munsen and Morrin
β	23	37	22W4	Red Deer River, east of Delburne
γ	22	32	21W4	Red Deer River, west of Rowley
δ	5	29	21W4	Horseshoe Canyon
WL	8	48	27W4	Wizard Lake
HH	35	30	17W4	Delia

Fresh samples of the Battle Member were particularly difficult to obtain due to the thick weathered crust that always covers the outcrops of this recessive unit. It was often necessary to dig for up to one meter below the "frothy" or "popcorn weathered" surface in order to reach reasonably fresh material.

FIELD DESCRIPTION OF THE UNITS

Detailed lithologic descriptions of some of the sampled sections are given in Appendix A.

Battle Member of the Edmonton Formation

The Battle Member occurs as a blocky, dark grey to brown claystone weathering in a characteristic mauve-brown to dark brown "frothy" surface. It is bound at the base by light grey to whitish weathering claystones, siltstones, and sandstones. At some places (Horseshoe Canyon) a band of light grey fine sandstone is present above the first meter or two of dark claystone. Toward the upper part of the unit, a hard, grey siliceous bed, 15 to 35 cm. (6 to 14 inches) thick (Kneehills Tuff bed), is present often accompanied by one to three less hard and thinner grey bentonite layers.

The Battle Member has been observed by the writer and by other authors in outcrops as far north as Whitecourt and as far south as Gleichen. It has been recognized in outcrops and in the subsurface by Ower (1960) and Elliott (1960) as present in a northwest-southeast trending band approximately 220 miles long (from Whitecourt to Calgary)

and more than 100 miles wide (from the eastern edge of the Foothills to 30 miles southwest of Edmonton). To the author's knowledge the unit has never been positively recognized in the Foothills. It is not present east of the above-mentioned band due to the west-southwest regional dip that brings to the surface older portions of the Edmonton Formation. Therefore, the depositional boundaries of this "almost unbelievably continuous marker" (Elliott, op. cit.) are not known.

The thickness of the Battle Member, as observed in outcrops, varies from three to fourteen meters (10 to 42 feet). No inferences can be drawn from the thickness of the units as to the original geometry of the sedimentary body because of erosional phenomena appearing at the top of the Battle Member. Ower (op. cit.), Clemens and Russell (1965), and Srivastava (1965) have reported erosional episodes affecting this unit. Local channelling and consequent reduction of the dark claystone can be observed at several localities. At the Scollard locality (section M of Appendix A) it is directly overlain by a breccia of mud pebbles in a silty matrix, probably indicating local erosion with short transport. The thickness of the Battle Member is also reduced in outcrops by local slumping of the overlying beds. The slumping occurs within the claystone, which plays the role of a lubricating horizon. On the banks of the Red Deer River in the Scollard area it is not uncommon to see the Battle Member overlie almost horizontal layers of fine clastic sedimentary rocks, whereas the overlying beds of sandstones and siltstones are tilted. In one instance the overlying beds are almost vertical and the thickness of the dark claystone is reduced to approximately three meters (10 feet).

Battle Formation

Lithology and megascopic aspect are identical to that exhibited by the Battle Member of the Edmonton Formation. The hard, grey siliceous bed and the less hard, grey bentonitic layers are present at the Quarry 45 locality (section S) near Elkwater in the Alberta portion of the Cypress Hills. An indurated grey bentonitic layer is present at Adams Creek (section J), but at the two localities (sections H and T) near the town of Eastend, Saskatchewan, the upper part of the Battle Formation seems to be absent. These data are in agreement with the observations of Clemens and Russell (1965) and the suggestion that an unconformity may cut much or all of the Battle Formation there.

Kneehills Tuff Bed

In the original description by Sanderson (in Allan and Sanderson, 1945): "The Tuff is a pale grey, massive rock of very fine grain, it resembles a rough surfaced felsite, or massive limestone. The rock is hard and can be trimmed like an igneous rock. It rings under the hammer. Upon weathering the exposed surface bleaches to a much lighter shade than the unweathered rock. The ash layer does not weather readily but breaks into sharp edged, angular fragments and forms a surface talus". Byrne (1951) reports three such beds within the Battle Member at a locality "thirty miles southwest of Edmonton". Ritchie (1960, p. 339) states: "In outcrop the tuff may occur as a single bed less than 10 inches thick or it may occur as two, three or four thin 2-inch beds within a interval of 5 to 6 feet in the upper part of the Dark Zone." In the present investigation, thin layers of grey, indurated bentonite have often been found associated

with the typical Kneehills Tuff _sensu_ Sanderson (_op. cit._), or even in places where the latter seemed to be missing. They are, however, very easily distinguishable from the hard, light grey bed by their fissility and their occurring in thinner units. Moreover, there is a very simple discriminatory test that can be used: the thin grey bentonitic layers disaggregate readily in water, while the typical Kneehills Tuff does not. The writer has never noticed in any section of the Battle Member more than one such hard, massive bed, with vacuoles often filled by opaline silica, brown bentonitic clay and at times pinkish-white minerals probably belonging to the family of the zeolites. The thinner bentonitic layers can also be considered tuffaceous. Pyroclastic components are undoubtedly present throughout the whole of the Battle, but the name Kneehills Tuff (bed) should be restricted to the bed that fits the original description by Sanderson (_op. cit._). The bed is generally present in the upper portion of the Battle and its occasional absence seems to be due to erosion or local slumping. Its continuity can be traced for long distances in outcrop. The fact that it occurs always near the top of the Battle, within an interval of few meters supports the interpretation of one main silicified tuff bed only.

Sediments Underlying the Battle Member

No formal name is here given to the sediments underlying the Battle Member. The term _White sandstone_ proposed by Sanderson (in Allan and Sanderson, 1945), although locally useful and justified, cannot be applied in dealing with a wide area since it was based on the identification of a local thin coal seam as the lower boundary.

The Battle Member is generally underlain by light grey to white weathering claystones, siltstones and/or sandstones. At places a claystone is in direct contact with the dark unit, whereas at other localities a sandstone occurs instead. In a general way a "White Zone" is present and easily noticeable because of the chromatic contrast with the "Dark Zone". It is, however, difficult to delimit the lower boundary of the "White Zone". A coal seam is sometimes present, but at other places it is missing, and some lenses of coal may occur almost at the contact with the Battle Member (see Appendix A). In the Wizard Lake core the dark claystone is underlain by two meters (6'10") of light colored claystone and siltstone below which a body of light grey sandstone, eighteen meters (60') thick, is present extending down to a thin layer of brown carbonaceous shale. It would be advisable to revise the terminology of the Edmonton Formation and to include in one single unit all the sediments between the Battle Member and the next lower conspicuous marker (Drumheller marine tongue). This would be an easily recognizable division, at least in southern Alberta.

Whitemud Formation

The Whitemud Formation will not be discussed in detail in the present work. It consists of an assemblage of white to light grey mostly kaolinitic clays, siltstones and sandstones and thin lignitic beds underlying the Battle Formation and overlying the Eastend Formation, in the Cypress Hills area. The reader is referred to work by Russell (1932), Fraser _et al_. (1935), Furnival (1946), Kupsch (1956), and Byers (1969) for more information. Detailed lithologic descriptions of sections of the upper part of the Whitemud Formation are given in Appendix A.

CHAPTER THREE - MICROSCOPIC DESCRIPTION

BATTLE MEMBER AND BATTLE FORMATION

The dark claystones of the Battle Formation and those of the Alberta equivalent appear to be identical on microscopic examination.

Thin sections of the dark claystones of the two units reveal an unusual sedimentary microfacies, viz. a claystone containing an abundant silt fraction composed almost entirely of silicified vegetal fragments with a few sand-size grains, among which silicified vegetal fragments are also abundant.

Although no distinct bedding was observed in the field, some thin sections display a fine layering of clayey and silty bands (Pl. XV and Pl. XVI A). The thickness of the individual laminae varies between 0.1 mm and 1 mm. Often, the layering is confused by festoon-like bands of clay, and in some thin sections the claystone appears completely structureless.

The silt and sand fractions were studied both in thin section and in grain mounts. The silt fraction between 8 and 30 microns is made up almost entirely of silicified (opaline) pollen grains, microspores and other vegetal fragments some of which are of fungal affinity. The fraction between 30 and 74 microns is composed of opaline elongate tracheary elements and fragments of megaspores, angular quartz grains, and partly devitrified glass shards of light brown color and typical lunate shape. A few bipyramidal quartz grains and zircons with perfectly pointed terminations were also observed.

Other minerals found in the dark claystones of the Battle include opaque iron oxides and ilmenite, green and brown biotite, garnet, and concretionary small spheres (less than 1 mm in diameter) of gypsum and calcium carbonate.

The microfacies of the claystone is illustrated in Plate XVI B, C, D, E, F, G, where some of the typical microfossils of the Battle are shown.

The grey bentonites associated with the Kneehills Tuff bed show a greater abundance of volcanic elements. Glass shards and broken glass bubbles of the type illustrated by Ross and Hendricks (1945) from bentonites of California and Nevada occur here in great abundance (Pl. XVI, H and I). Silicified vegetal fragments are still present but the ratio of shards to vegetal fragments is higher than in the dark claystones.

KNEEHILLS TUFF BED

Sanderson's (in Allan and Sanderson, 1948) original description of the Kneehills Tuff in thin section reads: "Microscopically this rock is seen to be made up of minute, fresh mineral fragments, quartz and feldspar mainly, with varying proportions of altered glass, all set in a felty groundmass which is isotropic to dimly anisotropic. It is thought that the groundmass is made up essentially of devitrified glass along with minute masses of fibres of redeposited chalcedonic or opaline silica". A number of thin sections examined by Ritchie (1957) led to the classification of the Kneehills Tuff as a vitric-crystal tuff after Heinrich (1956).

Upon microscopic examination of thin sections of the tuff from several localities (Figs. 3 and 4) the only new observation that can be made here concerns the presence in the tuff bed of the same type of silicified vegetal fragments (spores, tracheary elements, etc.) already noted in the dark claystones of the Battle. They occur in lesser number than in the claystone and are easily confused in thin section with the associated glass shards (Pl. XVII G and H). The opaline silica of which they are made has optical properties very similar to the glass and the random cut of a tracheary element often produces the curved or lunate shape characteristic of volcanic shards.

Examination of the vugs in the tuff reveals the presence of a greater number of mineral types than chalcedony and bentonite (Sanderson, op. cit.). Members of the zeolite group and Fe hydroxides occur together with other minerals that have not been identified.

The heavy minerals of the Kneehills Tuff have been studied by Ritchie (op. cit.) and compared with the ones obtained from the Butte rhyolite, an Upper Cretaceous extrusive of Montana. The similarity of the two suites, the presence of the same types of zircon, and the consideration that the Butte lavas are the only known extrusives in the general area that are contemporaneous with the Kneehills Tuff (Ritchie, op. cit.), point toward a southern provenance of the volcanic ash and dust that made up the bulk of this pyroclastic deposit.

Since a southern provenance of the volcanic material of the Kneehills Tuff would also be expressed by a decrease in grain size from

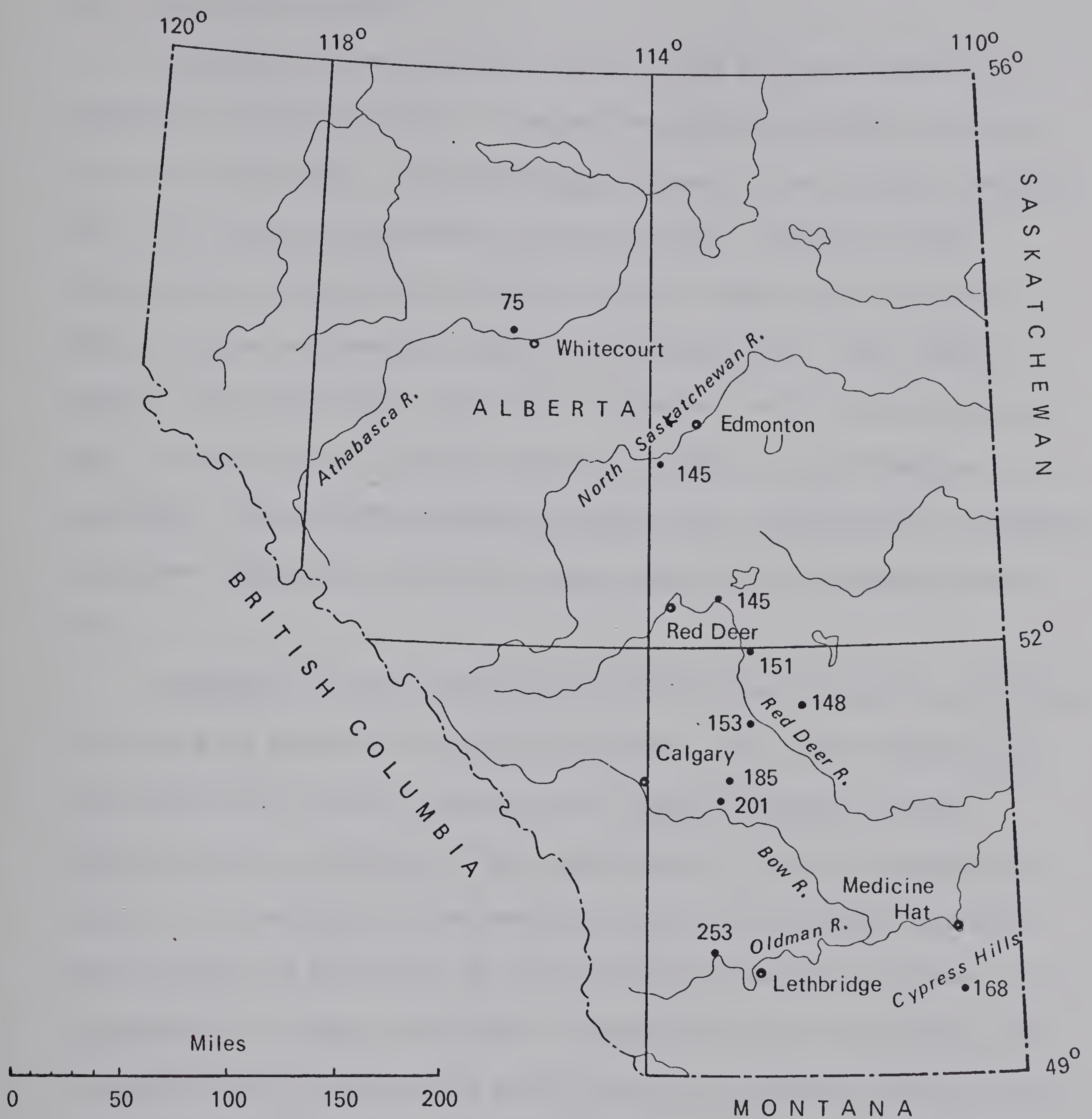


FIGURE 4

Distribution of the *coarse indices* of the Kneehills Tuff in southern Alberta

south to north, ten samples from outcrops of the tuff bed were selected for a grain-size study[1].

Outcrops of the Kneehills Tuff are more or less aligned in a north-south direction (Fig. 4), except for the Cypress Hills locality. East of the Hand Hills, older rocks are exposed at the surface, and the tuff, if it was ever deposited, has been eroded. Campbell (1962) reported that the Kneehills Tuff bed and the "mauve shale" (Battle Member) outcrop at Shearness, east of the Hand Hills. Bihl (1968), however, has convincingly shown that the "mauve shale" of Shearness is older than the Battle Member since it contains a Lower Edmonton microflora. No reliable subsurface samples were available from localities to the west where the tuff bed has been encountered in numerous drill holes.

Windborne volcanic ashes and dust show size-sorting by gravity and the grain size decreases away from the source. The only exceptions to this general rule are the ignimbrites or <u>nuées ardentes</u> that are deposited under conditions of "hot turbidites". Since no ignimbritic feature is to be found in the Kneehills Tuff, one can safely assume a normal pattern of deposition of the original volcanic ash and dust. In a lacustrine or swampy environment of deposition little reworking is to be expected, and therefore the grain size of the tuff bed should reflect distance from the source. Diagenesis might have altered the original texture of the pyroclastic deposit in such a way that it would be extremely

---

(1) This section on the provenance of the Kneehills Tuff has already been published (Binda, 1969).

difficult to find the original grain-size distribution preserved in the medium to fine fractions. The coarse fraction, which is relatively less affected by diagenetic changes and much easier to measure in thin section, provides the most reliable grain-size parameter. Composite grains made up of one or more crystals plus glass were not detected in thin sections of the Kneehills Tuff, but it is quite possible that some of the grains of the original dust were of a composite nature. The largest crystals of the tuff would, however, still give a reasonable picture of the size distribution unless one assumes that the majority of the particles transported by the wind were composite grains. Moreover, the coarse tail of any size-distribution curve is particularly sensitive to the energy of the transporting medium, as shown by Doeglas (1946) and Passega (1957).

Since it was impossible to disaggregate the rock without obliterating the original textural characteristics, a thin-section method of study was devised. The longest intercept of the seventy-five largest quartz grains that did not show evidence of authigenic overgrowth or solution were chosen. Of the seventy-five measurements, the twenty-five smallest were discarded and the arithmetic mean of the remaining fifty was calculated. In order to check the reliability of the results and the possibility of "operator's error", some of the measurements were repeated at different times and some were also duplicated by colleagues at the Department of Geology, University of Alberta. Since the differences between the arithmetic means were never greater than 5%, the measurements were accepted as reliable.

The arithmetic mean of the fifty largest grains over a more or less standard thin-section area is here referred to as the <u>coarse index</u>. The coarse index is derived from analogous parameters already in the literature,

such as the <u>clasticity index</u> (Carozzi, 1956, 1958) and the <u>one-percentile</u> (Passega, 1957). The application of the clasticity index, or measurement of the apparent largest diameter in thin section, to the ten thin sections of the Kneehills Tuff did not show any significant pattern. It was found that a pattern started emerging when the mean of twenty measurements was taken. If the mean of the fifty largest diameters is taken, however, the errors derived from random cutting of the grains is lessened; at the same time the method is still quick enough to be of practical application.

Figure 4 shows the geographic distribution of the coarse indices of the ten samples under study, over a distance of slightly more than 300 miles from the outcrop on the Oldman River (south) to the one on the Athabasca River (north). The values decrease from 253 to 75 microns. The decrease is gradual and continuous with only a slight overlap of the values towards the central part (see also Pl. XVII C, D, E, and F). Of the ten values of Figure 4, only the one from the Cypress Hills (south-eastern corner of the map) appears to be anomalous. The low index of this sample could be due to a west-east component of the direction of transport but it can also be explained with a south-north transport direction. The study of recent volcanic ejecta by Minakami (1942), Thorarinsson (1954), and others, shows that volcanic clouds of dust and ashes tend to spread as elongated lobes. One might therefore expect a somewhat more rapid decrease in grain size in directions at an angle to the long axis of the lobe than along the axis. The present distribution of the outcrops makes it impossible to reconstruct the original lobe with any degree of certainty. The areal distribution of

the coarse indices clearly shows that the southern source postulated by Ritchie (1957) on the basis of the heavy mineral suite, is supported also on the basis of grain-size analysis.

Two of the samples selected for this study were collected from outcrops remote from the area where the Kneehills Tuff can be followed as a continuous unit in the field. The southernmost sample (coarse index 253) comes from an outcrop on the Oldman River where the Kneehills Tuff has been identified by Tozer (1952). The northernmost sample (coarse index 75) comes from an outcrop on the Athabasca River where the tuff bed has been identified as Kneehills by Folinsbee (pers. comm.). Even if the values of these extreme samples are discarded due to uncertain correlation, the south-north trend of the coarse indices would still be evident from the values of the intervening samples.

SANDSTONES UNDERLYING THE BATTLE MEMBER OF THE EDMONTON FORMATION

Twenty-three thin sections of sandstone samples from below the Battle Member, of which eleven are from the Wizard Lake core and twelve from four different localities of southern Alberta, were analyzed by point count method. Most of the thin sections were stained with sodium cobaltinitrite for a fast identification of the K-feldspars. Some were left unstained in order to see finer details of the groundmass that are sometimes obscured by the staining. Two hundred points per thin section were identified and tabulated as quartz, feldspars, mica, rock fragments, others, or groundmass. The results of the point count are given in Tables II and III.

TABLE II

Composition* of Sandstones of the Middle Member of the Edmonton Formation
(Samples from the Wizard Lake Core)**

Sample No.	RC/S35	RC/S36	RC/S37	RC/S38	RC/S39	RC/S40	RC/S41	RC/S42	RC/S43	RC/S50	RC/S52
Quartz	16	24	23	28	32	20	26	28	23	24	28
K Feldspar	4	5	8	9	7	6	9	8	4	10	4
Plagioclase	2	1	1	5	3	2	2	3	3	3	2
Mica	1	3	3	2	3		1	3	1	2	
Others		1	5	2	1				1		
ROCK FRAGMENTS	34	48	48	42	41	47	58	41	62	34	52
Chert	(9)	(11)	(8)	(11)	(8)	(18)	(17)	(7)	(29)	(2)	(9)
Volcanics	(19)	(19)	(19)	(22)	(19)	(17)	(19)	(14)	(10)	(15)	(23)
Others	(6)	(18)	(21)	(9)	(14)	(12)	(22)	(20)	(23)	(17)	(20)
GROUNDMASS	43	18	12	12	13	25	4	17	6	27	14
TOTAL	100	100	100	100	100	100	100	100	100	100	100

* 200 points counted. Percentages approximated to the nearest round figure.

** Slides RC/ were made available for study by the Research Council of Alberta.

TABLE III

Composition* of Sandstones of the Middle Member of the Edmonton Formation
(Samples From the Red Deer River Valley and Horseshoe Canyon)

Sample No.	U5	U9	U10	D1	D11	A17	A18	A19	A21	B1	B2	B3
Quartz	34	25	22	32	24	28	30	28	33	32	31	33
K Feldspar	8	12	10	8	5	12	7	6	8	5	6	8
Plagioclase	1	4	1	1	1	2	1	1	1		1	2
Mica	3	1		2		1		2	1		2	
Others		1	1			1						
ROCK FRAGMENTS	31	31	36	39	35	31	32	42	24	34	30	35
Chert	(6)	(3)	(9)	(7)	(6)	(9)	(9)	(10)	(8)	(7)	(6)	(8)
Volcanics	(8)	(10)	(10)	(12)	(6)	(14)	(9)	(9)	(2)	(5)	(10)	(8)
Others	(17)	(18)	(17)	(20)	(23)	(8)	(14)	(23)	(14)	(22)	(14)	(25)
GROUNDMASS	23	26	30	18	35	25	30	21	33	29	30	22
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100

* 200 points counted. Percentages approximated to the nearest round figure.

Essential Components

The components used for the classification of the examined samples are: quartz, feldspars and rock fragments. The composition and classification of the sandstones is expressed by the triangular diagram of Figure 5 where the percentages of the essential components have been recalculated to 100 percent and plotted.

Quartz

Quartz grains make up 25 to 59 percent of the essential components of the examined sandstones from the Middle member of the Edmonton Formation. The most common type of quartz is a "single grain, straight extinction" or "single grain, slightly undulose extinction" (types A1 and A2 of Folk's 1961 empirical classification). Such types were previously treated by Krynine (1940) as "normal igneous quartz". Folk (op. cit.) in his genetic classification modified after Krynine's, grouped them under "common (plutonic) quartz".

Blatt and Christie (1963) after examining a large number of plutonic metamorphic and volcanic rocks, showed that quartz with non-undulatory extinction, scarce in intrusive igneous rocks (13%), is very abundant only in extrusive igneous rocks (90% of the total quartz). Since the sandstones of the Edmonton Formation are rich in volcanic rock fragments, it is fairly safe to assume that at least part of the non-undulatory quartz must have derived from extrusive rocks. There is also a distinct possibility that a large amount of non-undulatory quartz in sandstones might derive from the breaking of polycrystalline quartz grains along the boundaries of the individual crystals (Blatt, 1967).

Polycrystalline quartz is also common and it is present in three basic types: polycrystalline grains with straight boundaries between equant interlocking grains (Pl. XIX A); polycrystalline grains with sutured boundaries between individual crystals that show a bimodal size distribution (Pl. XIX B); polycrystalline grains with sutured or crenulated (Folk, op. cit.) boundaries between the elongated individuals (Pl. XIX C). Although none of these types is restricted to any particular rock-type, the quartz of Plate XIX A is more often derived from igneous plutonic rocks and quartzites, whereas those of B and C are related to metamorphic sources (Blatt, op. cit.), with type C suggesting quartz commonly found in schists.

Rounded quartz suggesting more than one cycle of erosion, transport, and deposition, is also fairly common in the sandstones of the Middle member (Pl. XIX D). Also present, although not common, are: quartz with vermicular inclusions of chlorite (Pl. XIX E) of the "vein" type (Folk, op. cit.) and myrmekite fragments showing a vermicular intergrowth of an albitic plagioclase and quartz. The presence of bipyramidal volcanic quartz in the sandstones is suggested by occasional grain sections.

Feldspar

The content of feldspars of the examined sandstones from the Middle member of the Edmonton Formation varies from 7 to 19 percent of the essential components. Both K and Na-Ca feldspars are present, with potassium feldspar exceeding the plagioclase by a ratio varying between 4/3 and 8/1. Among the K feldspars orthoclase is the most abundant; it

is usually untwinned, but grains showing Carlsbad twinning are not uncommon; it is almost always cloudy due to alteration. Sanidine grains, less altered and distinguishable from orthoclase by their low 2V, are also present, together with microcline. Plagioclase occurs as fresh grains (Pl. XIX F) or as intensely saussuritized grains in which only a trace of the polysynthetic twinning is recognizable.

Rock Fragments

Rock fragments are the major constituent of the sandstones of the Middle member. They make up 31 to 62 percent of the essential components. Three groups have been differentiated in this study: Chert, Volcanics, Others.

Chert

Chert fragments composed of interlocking equants of microcrystalline quartz or chalcedony sometimes in contact with patches of coarser crystalline quartz are abundant. The elongated shape of the coarser-grained patches suggests that they might have been microscopic veins in the original chert. The chert fragments almost always have a disseminated black or green pigmentation that makes them easily recognizable under parallel polarized light. Microfossils of uncertain affinity have been observed in some chert fragments. In Plate XX some of the fossil organic remains are illustrated: Plate XX B shows rounded structures, approximately 0.1 mm in diameter suggesting radiolarians; C and D also show very small microfossils whose affinities are not clear; E illustrates a chert fragment displaying spherical radiate

structures 0.05 mm in diameter. These spherical structures are probably inorganic in origin (spherulites).

Volcanic rock fragments

Volcanic rock fragments are very abundant in these sandstones. The most common type is illustrated in Plate XIX H; it displays a trachytic texture with laths of feldspar preferentially oriented in a glassy groundmass. Such grains are generally stained by sodium cobaltinitrate but they are easily distinguishable from feldspars by the characteristic texture. Other types of volcanic rock fragments show less conspicuous features. They can usually be recognized by the presence of feldspar phenocrysts in a glassy groundmass. It is felt here that the percentages of volcanics at Tables II and III are probably lower than real, owing to the fact that it is not always easy to identify volcanic grains. Furthermore, their features are sometimes completely obliterated by alteration and thus many of them have probably been classified either as "others" or as "groundmass".

Others

Under this heading have been grouped all the rock fragments not identified as "chert" or "volcanics".

Sedimentary rock fragments of shales and siltstones are rather common (Pl. XX A). Some of the fragments identified as shales probably belong to sediments that have been subject to a certain degree of metamorphism. Thin parallel bands of mica can be observed in some of these rock-types. Among the unidentified rock fragments that have been

placed in this category are those grains that have been almost completely altered to clay minerals but whose outlines are still visible; if an outline was not visible, the point under the cross-hair was as a rule counted as "groundmass".

Minor Components

Minor components are those minerals that do not enter into the classification of the sandstones. For the purpose of this study they have been subdivided into "Mica" and "Others". Due to the limited number of points counted, the quantitative estimates of minor components in Tables II and III are not precise.

Mica

Both muscovite and biotite are present in the samples, the latter being generally more abundant. Both brown and red varieties of biotite have been observed. Chlorite, mainly of the variety penninite, has been frequently noticed. Some of the chlorite was formed as an alteration product of biotite, and biotite flakes which are almost completely chloritized can be observed.

Others

Among the other minor components, garnet, zircon and epidote are the most common detrital elements. By far the most common non-detrital mineral is siderite that at times occurs abundantly as authigenic micronodules formed around biotite flakes which they gradually replace

(Pl. XXI E). Some siderite nodules of the Edmonton Formation and spherulites of the Whitemud Formation are dealt with in detail in a separate section.

Heavy Minerals

Twelve mounts of minerals of specific gravity higher than 2.95 (Tetrabromoethene) were prepared from sandstones of the Middle member of the Edmonton Formation (samples A17, A18, A19, B2, O1, U4, U11, WL12, WL27, α7) and from the Whitemud Formation (S16, S31). The standard laboratory procedure without the use of acids as described by Chi (1966) was followed. The following mineral suite was observed (in order of decreasing abundance).

Garnet is abundant in most slides of the Edmonton except the ones from Horseshoe Canyon, where it is present only in A17, it is abundant in one sample of the Whitemud, absent in the other. It generally occurs as angular fragments with subconchoidal to conchoidal fractures and only very few euhedral grains were noticed. Colorless and pink varieties are the most common, but a few green, yellow and brown grains are present.

Zircon is abundant in samples from Horseshoe Canyon, common in most of the others. The various types of zircon in the analysed samples include: colorless euhedral, colorless subhedral (showing some rounding), colorless anhedral (rounded), pink rounded or subrounded. The colorless varieties display inclusions such as apatite needles and gas bubbles.

Apatite is fairly common in most samples but absent in samples from Horseshoe Canyon. It occurs mostly as colorless euhedral to subhedral crystals devoid of inclusions. A few grains show dark portions parallel to the C axis.

Tourmaline of brown, pink, green and blue varieties is found in all the slides ranging in frequence from common to rare.

Epidote and rutile are also present in most of the samples.

Other minerals that have been noted in small amounts in the analyzed samples include: allanite, andalusite, biotite, chlorite, clinozoisite, collophane, kyanite, sphene, staurolite. A few grains of hornblende have been seen in only one sample (WL12) of the Edmonton. A number of opaque minerals is also present, with leucoxene the most common.

"Groundmass"

The descriptive term "groundmass" is here conveniently adopted for all interstice-filling material present between recognizable grains. It therefore includes matrix and cement, terms under which the finer than 0.03 mm (Doty and Hubert, 1962) and the chemically precipitated binding materials in sandstones are respectively classified by sedimentary petrographers.

Krynine (1948) discussed the use of the term matrix and concluded that the term is purely relative to the grain size of the rock (*i.e.* sand size grains would be called matrix in a conglomerate, whereas in a sandstone the term would be applied to clay size particles). A genetic connotation is, however, attached to the word matrix as it is

used by Pettijohn (1957), Carozzi (1960) and several others to identify detrital particles of smaller size than sand and silt size. Such particles would be deposited simultaneously with the sand or introduced at a later stage, but always as a detrital mud. In the examined samples some of the clay material present between recognizable sand grains derives from the *in situ* alteration of rock fragments. Plate XVIII E and F shows rock fragments being partially invaded by a montmorillonitic clay. Plate XVIII D shows grains completely replaced by a felt-like mass of montmorillonitic clay; only the outline of the original grains is just barely visible. It seems more reasonable to think that this alteration has taken place *in situ*, mostly due to the devitrification of the glass of the volcanic fragments (Ross and Hendricks, 1945) rather than assume that such grains were deposited in the present state. Upon complete destruction of the volcanic rock fragments, all the glass is altered to montmorillonite and some phenocrysts are preserved in the clayey mass. It is then impossible to distinguish between such type of alteration product and material that might have been deposited as detrital matrix.

It is felt that a great deal of the clay-size material derives from *in situ* chemical alteration of the grains and therefore should be called cement. This opinion is also shared by other workers who examined the same rock types (Carrigy, pers. comm.). However, since a more precise determination is impossible, the convenient term groundmass is applied for both matrix and cement. This also includes material that can be called cement in the classical sense, and three main types of cement have been observed in the sandstones of the Middle member.

Montmorillonite cement is present in all the examined samples. It occurs as thin rims of a pale tan color surrounding detrital grains similar to the ones described by Lerbekmo (1957) from Tertiary sandstones of California. Probably also some authigenic veins of the type illustrated in Plate XVIII G are montmorillonitic.

Kaolinite cement is common although less abundant than montmorillonite. It occurs as microcrystalline aggregates filling intergranular spaces (Pl. XVIII H). These aggregates resemble detrital microcrystalline chert but can be distinguished from the latter by their lower refractive indices, by their characteristic texture of closely packed individual particles or "books", and by the lack of detrital shape. As to the origin of the kaolinite there are two possibilities: by alteration of feldspars, or, as an end product of weathering. Kaolinite would, according to Ross and Hendricks (op. cit.) form from montmorillonite "under continued leaching by acid waters or by long-continued leaching in neutral waters under oxidizing conditions".

Montmorillonite and kaolinite cements in sandstones of the Edmonton Formation rich in volcanic rock fragments have been reported and described by Carrigy and Mellon (1964).

Calcite cement is not very common in these sandstones, but it occurs in great abundance in a few of them. In sample RC/S40, for example, it predominates over montmorillonite and kaolinite together by a ratio of 7 to 1. Both granular and fibrous calcite cements of the same types described by Chi (1966) from sandstones of the Upper Edmonton and the Frenchman Formation have been observed in the samples.

Roundness and Shape

Visual estimates of grain shape in thin section by means of the chart published by Krumbein and Sloss (1963) gave average roundness values around 0.1-0.3 for the quartz grains and somewhat higher values for the rock fragments (0.3-0.5).

If the Powers (1953) scale is used, the quartz grains would fall in the first three classes, very angular to subangular (Pl. XVIII A, B, and C). No regional or vertical variation in roundness was detected in the samples from this cursory examination and it was felt that little additional information could be gained from a systematic analysis.

Sphericity, as it can be estimated in thin section by the Krumbein and Sloss chart, is generally around 0.7, with, however, a fairly large number of grains displaying a more elongate shape (between 0.3 and 0.5).

Classification

Classifications of sandstones are plentiful in the geological literature. They may be descriptive, genetic, or a combination of the two. Klein (1963), McBride (1963), and Boggs (1967) review and discuss the literature on the subject. In general none of these classifications can be satisfactorily applied to all types of sandstones, although each seems to work very well at least for the particular set of rocks that the author of the classification had in mind when he devised it. The strongest disagreement exists on the choice of the end members, and especially on whether clay matrix should be considered an essential component for classification. Clay has been used as an end member by Pettijohn (1957) and Gilbert (1954), to mention only two out of several.

When a sandstone contains more than 15 percent detrital matrix it qualifies for the name graywacke according to Pettijohn (op. cit.).

On the other hand, Folk (1954) excluded clay matrix from the essential components and used quartz, feldspar, and rock fragments as end members of the triangle. Sandstones containing abundant rock fragments are then, according to Folk (ibid.), to be called graywackes.

Gilbert (1954), followed by Dott (1964), divided all sandstones into arenites (less than 10% clay matrix) and wackes (more than 10% clay matrix). Within these two large categories, triangular diagrams with quartz, feldspar, and rock fragments are then used for classification.

Most of the sandstones of the Edmonton Formation would meet all the requirements for graywackes both sensu Pettijohn and sensu Folk (1954) since they are rich in clay as well as in rock fragments. According to Gilbert's classification they should be called lithic wackes. However, the writer feels that the term graywacke, and its derivatives, should not be used for the sandstones of the Edmonton Formation since a genetic significance tends to be attached to it. Graywackes, especially in European geology, are the immature marine sandstones of the Flysch facies. They are generally dark colored and display a host of megascopic features that make them totally unrelated to the sandstones of the Upper Cretaceous of Alberta and Saskatchewan. In the 1968 edition of "Petrology of Sedimentary Rocks", Folk (see reference Folk, 1961) proposed that the term graywacke be dropped from the petrological classification of sandstones and used only as a field term.

Travis (1955) proposed a classification in which only the sand-size clastic grains are considered essential components, chert is

incorporated with the rock fragments, and the term graywacke is avoided. According to this classification (Fig. 5) the sandstones of the Middle Edmonton range from lithic sandstones to rock fragment sandstones, thus showing perfect agreement with the sandstones of the Upper Edmonton studied by Chi (1966).

Remarks on the Origin

The mineralogic and lithic assemblage of these sandstones indicates a source area in which a wide variety of rock types were present. Volcanics, sediments, acid and basic igneous rocks, pegmatites, and both low and high rank metamorphic rocks are indicated as a prime source by light and heavy fractions. The most indicative elements are probably the microfossil-bearing chert fragments of Plate XX B, C, and D. Although the microfossils are not identifiable at a precise level, the chert fragments are likely to have come from Paleozoic rocks. The relative abundance of volcanic, chert, and sedimentary fragments and the scarcity of metamorphic lithic grains would, therefore, tend to exclude a provenance in the Precambrian Shield, and indicate as a likely source the general area of the Cordillera.

The sandstones of the Middle Edmonton can be considered immature, both compositionally (Pettijohn, 1957) and texturally (Folk, 1961). All their characteristics, together with the absence of marine indicators such as marine microfossils and glauconite, and their association with claystones bearing a continental microflora, points toward a fluviatile depositional environment. The complex of sedimentological features that characterizes these sandstones has been interpreted as a set of diagnostic

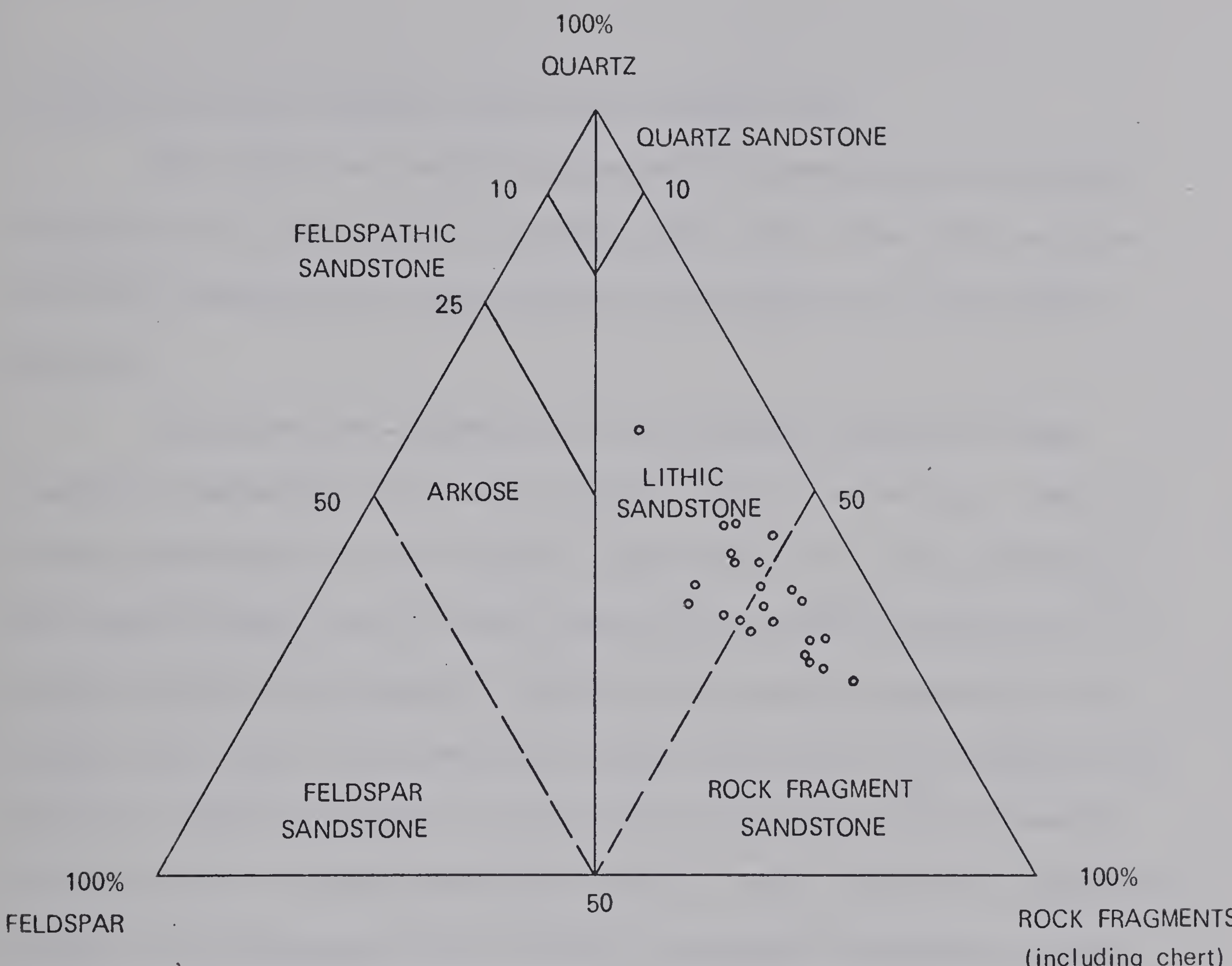


FIGURE 5

Composition of sandstones of the Middle Edmonton Formation and classification according to Travis (1955)

criteria for a fluviatile depositional environment by Paine and Meyerhoff (1968) in a study of the Catahoula Formation of western Louisiana.

SANDSTONES OF THE WHITEMUD FORMATION (CYPRESS HILLS)

The sandstones underlying the Battle Formation in the Cypress Hills have not been studied in detail here. Only a few thin sections have been examined for comparison with the sandstones of the Middle Edmonton.

In general the sandstones of the Whitemud display the same textural immaturity as the ones from the Alberta equivalent. They are lithic sandstones to rock fragment sandstones rich in clay groundmass. The quartz grains show the same general poor rounding exhibited by the quartz grains of the Edmonton Formation and they are generally of the single grain type, polycrystalline grains being rare. The lithic fragments are rather indistinct, being poorly preserved; they are mostly altered grains of microcrystalline nature. Byers (1969) in a comparative study of the petrology of the Whitemud and Eastend Formations, states that the sandstones of the Whitemud are characterized by the abundance of metamorphic lithic fragments whereas volcanic lithic fragments are abundant in the Eastend. Two thin sections of the Whitemud from Quarry 45 (S17 and S18) show a fair number of rock fragments of the same type as the one illustrated by Byers in Figure 4 A and described as "volcanic lithic fragments". Most of the grains are, however, unidentifiable. No fresh feldspars have been positively identified; some intensely sericitized and kaolinitized grains could conceivably have been feldspar or could have contained some feldspar.

Of the micas only muscovite is represented, biotite being completely absent, as already noted by Byers.

To summarize, the sandstones of the Whitemud lack the clearly recognizable volcanic grains of the Middle Edmonton and are also depleted in feldspars and biotite. Whether this can be attributed to a different source, to post-depositional alteration processes, or to a combination of the two, is not possible to say.

CHAPTER FOUR - GRAIN-SIZE ANALYSIS OF SANDSTONES

INTRODUCTION

Statement of the Problem

Grain-size analyses were carried out on 73 samples of the sandstones underlying the Battle Member, from ten different outcrop localities and one borehole (samples WL) in the Plains of Southern Alberta. Two samples from a sandstone overlying the Battle Member (E22 and E24) and three from the Whitemud Formation of the Cypress Hills (S34, S35, S36) were also analysed.

The purpose of the investigation was two-fold. The main object was to obtain more information on the depositional environment of the rocks immediately underlying the Battle Member and to compare the results of the mechanical analyses with the micropaleontological data. The second aim was to test whether or not some published methods for the discrimination of recent sedimentary environments by grain-size study could be applied to Cretaceous sandstones that have undergone some post-depositional changes.

To summarize the situation once again, several authors have suggested that the Battle Member (Kneehills Tuff horizon, Mauve Shale, Blackmud) might be marine in origin. The stratigraphic succession underlying the Battle consists of siltstones, claystones, sandstones, and coal seams. In the whole of the Edmonton Formation, only the Drumheller Marine Tongue shows fossil remains other than continental in origin. As discussed in detail in Chapter Seven of this thesis, all the microfossils recovered from either the Battle or the underlying

sediments belong to the continental milieu, with complete exclusion of any indicator of marine environment.

If the Battle had been deposited in a marine environment, one would expect to find some sign of the transgression from continental to marine milieu in the sandstones underlying it. Beaches or marine bars or some other type of nearshore deposit formed under energy conditions characteristic of the zone above wave base would be present. Therefore in this study emphasis will be laid on contrasting grain-size characteristics of beach and river sediments.

The discrimination of the various sedimentary environments in which a sandstone can be formed, by means of grain-size parameters, has long been one of the main aims of sedimentary geologists. The grain-size approach has ardent supporters as well as openly declared enemies among geologists, and some feel that the interpretation of sedimentary environments by grain-size will never succeed. To quote Friedman (1967, pp. 351-352), however:

> "The size frequency distribution approach is not meant to replace other geological analytical techniques but can usefully supplement them. No single approach can uniquely define depositional environment in ancient equivalents; but size frequency studies, if properly applied and if their limitations are realized, can help in up-grading the odds in environmental interpretation."

Grain-size studies date back from the end of the nineteenth century, and among the most significant work published before the Second World War are the classic papers by Udden (1898 and 1914) and Krumbein and Aberdeen (1937). In recent years, however, with the increased development of investigation of modern sediments, and the general trend to quantify geological data, a variety of approaches to

grain-size distribution of sands has appeared in the literature. It is beyond the scope of this study to give a complete survey of the literature on the subject, although some of the main methods and approaches will be mentioned in the appropriate sections. Excellent reviews of the literature can be found in Folk (1966) and Friedman (1967).

Silt and Clay Content

As already discussed in the petrography section, some of the clay in these sandstones is authigenic in origin, being a product of the alteration of volcanic rock fragments. It is virtually impossible to estimate how much of the fines (minus 62.5 microns) is primary and how much is secondary. Therefore it was not thought worthwhile to engage in laborious and time-consuming analyses of the minus 62.5 microns fraction, and only the coarse fraction (plus 62.5 microns) was analyzed. The distributions were recalculated to include the percentage of fines in order to draw the cumulative curves shown in Appendix B. The curves have been left open to the right. In each sample the fine fraction has probably received an increment from the diagenetic breakdown of some coarse grains. It is therefore with these limitations in mind that the grain-size analyses have to be accepted. In spite of this it is felt that the grain-size distribution can still give useful information. Total percentages have been used only in the calculation of the quartiles in the Q1 Md Q3 (Doeglas, 1968), in the plot of the C-M diagram (Passega, 1957), and in discussing the general types of cumulative curves. Standard deviation, which requires better information on the shape of the fine tails, has not been used for the whole curve. For approaches such

as the one suggested by Moiola and Weiser (1968) and multivariate analysis (Klovan, 1966), only the distribution of the plus 62.5 microns fraction has been taken into account. The results have been satisfactory enough to justify the method.

As to the minus 62.5 microns fraction, it can be observed (see Appendix B) that there is a direct correlation between percentage of fines and median diameter of the plus 62.5 microns fraction. Since the samples are petrologically rather uniform, there is no reason to assume that diagenetic changes were remarkably more effective on some samples than on others. Therefore it must be deduced that either a great deal of the fine fraction is primary, or that diagenesis affected fine grains more than it did coarse ones. If the first hypothesis is true, then the use of total percentages, at least for statistical parameters such as median, quartiles, and one-percentile, is justified. If the second hypothesis is true, there is a high probability that a large proportion of the diagenetic changes took place within the fine fraction itself, and therefore the weight percentages for the coarse fraction are not too biased. The general internal organization (Potter, 1967) of each sampled section which shows a decrease of the median diameter (and a correspondent increase in the percentage of the fine fraction) upward, would certainly favor the first of the two hypotheses, and therefore most of the fine fraction is considered to be primary. The fact that in several samples the fine fraction is only between 8 and 15 percent of the total sample, supports this view.

TECHNIQUES AND METHODS

Samples of approximately 50 grams of each sandstone were gently crushed with a rolling-pin on a cardboard base, weighed, and soaked in distilled water with a little common detergent for three to four days. Additional disaggregation was obtained by stirring the slurry for two to three minutes in a rotary blender. The samples were then wet-sieved through a 230 mesh (62.5 microns) sieve and only the coarse (plus 62.5 microns) fraction was kept for analysis. After oven-drying, the sands were dry-sieved again through a 230 mesh sieve, weighed, checked under a stereoscopic microscope to make sure that disaggregation was complete, and then split by Otto microsplitter to obtain samples ranging in weight from eight to ten grams. As the actual grain-size analyses were carried out at Scripps Institution of Oceanography, La Jolla, California, the last split of the samples was made on location, and final samples ranging in weight from three to five grams were obtained. Weights were measured to the third decimal place and the precision of the balance, as given by the manufacturer, was one milligram.

The grain-size analyses of the plus 62.5 microns fractions were made by settling tube. An excellent description of the apparatus used at Scripps, of the method, and of the theory of grain-size analysis by settling velocity, has been published by Sahu (1964) and these subjects will only be summarized here. The settling tube developed at Scripps by Dr. Tj. van Andel is a modification and refinement of the sedimentation balance developed by Doeglas (1946). It consists of a vertical glass tube 182.5 centimeters long and 7.8 centimeters in internal diameter. A wire extends vertically throughout the center of the tube, and a cup

is magnetically attached at the bottom of the wire. The tube is filled with degassed distilled water and the water is allowed to reach room temperature. Small (3 to 5 g.) samples of the sediment are poured into the tube from the top and their differential settling on the cup at the bottom is recorded as a measure of the strain on the wire. A strain-gauge connected to a Wheatstone bridge transfers the strain to an electrical potential difference amplified and recorded by a potentiometer. The measurements are recorded continuously to give the cumulative strain.

The principle on which this method is based is extremely simple and in effect it simulates the process of sedimentation as it occurs in nature. The particles fall through the tube in an aqueous medium and hit the cup at the bottom of the tube at times dependent upon their settling velocities, related to their "hydraulic value". By hydraulic value is meant (see Krumbein and Pettijohn, 1938 and Sahu, 1964) the "diameter of a quartz sphere having the same settling velocity of a given particle in water".

The transformation from settling velocity (terminal velocity) to particle diameter depends upon Reynolds number, drag coefficient, hindered settling, wall effect, shape factor, and advection in finer particles. Sahu (1964) has shown that, owing to the characteristics of the tube, and the amount and size of the sample used, hindered settling, wall effect, and advection currents are negligible in the size analysis performed with the Scripps apparatus. Tables for the transformation of terminal velocities to particle diameters, taking nominal diameters of quartz spheres as standard, are available for the Scripps tube. Sahu (ibid.) prepared a time-diameter graph that he used as an overlay on the cumulative curve obtained from the recorder, to read and record directly the cumulative

percentage of the size fraction. At present a computer program is used at Scripps to speed up operations; readings corresponding to settling times of quarter-phi fractions are entered and relative cumulative percentages calculated.

STATISTICAL PARAMETERS

Two sets of statistical parameters have been used in this study, one for the plus 62.5 microns fraction, and one for the total curves, inclusive of the fine fraction.

For comparison with results published by various authors, the grain-size is sometimes expressed in millimeters, or microns, and sometimes in the phi units ($\Phi = -\log_2 \xi$, where ξ is the diameter in millimeters for the Wentworth scale) of Krumbein (1934).

Sand Fractions

Median, mean grain size, variance, standard deviation and modes of the coarse fractions were calculated as part of the computer program for grain-size analysis at Scripps Institution of Oceanography. Of these, only mean and standard deviation were utilized. They had been calculated, at Scripps, using the following formulae (Inman, 1952):

$$\text{Mean} \quad \frac{\Phi\,16 + \Phi\,84}{2}$$

$$\text{Standard Deviation} \quad \frac{\Phi\,84 - \Phi\,16}{2}$$

The use of Inman's formulae for statistical parameters of these sands is justified by the fact that the size distributions of the coarse fractions are generally unimodal and approach a log normal distribution.

Total Curves

Very simple statistical parameters have been used for total curves. They are: One Percentile, First Quartile (25%), Third Quartile (75%), and Median (50%). They were all deduced graphically from the cumulative curves. Total cumulative curves were obtained by multiplying the cumulative percentages of the coarse fractions by the percentage of coarse fraction to total sample before loss of the fines.

RESULTS AND INTERPRETATION

Fine Fraction (<62.5 microns) and Internal Organization

It has already been discussed that, although some clay is undoubtedly authigenic, a good deal of the minus 62.5 microns fraction is certainly primary. A table showing the percentages of the fine fraction in the sandstones underlying the Battle Member is given in Appendix B; they range from eight to fifty percent. Samples containing more than fifty percent fine fraction are abundant at the contact with the dark claystone, but they have not been analyzed and are classified as siltstones, claystones, or shale. Very few samples, mostly from the basal part of the sandstone of the Wizard Lake core (section WL of Appendix B), contain less than fifteen percent fines, the average being somewhat higher. The significance of the minus 62.5 fraction in the detection of sedimentary environment has been discussed by Friedman (1967). In modern environments the fine tails that are characteristic of rivers are generally absent from beach sands. In the plot of skewness versus fine fraction Friedman (1967, p. 341, Fig. 17) shows that beach sands generally contain less than one percent fines, and only one sample shows

more than 3.5 percent. River sands, on the other hand, range from no fines at all to more than eight percent (out of plot).

Bagnold (1966) has shown that the minus 62.5 microns fraction is an essential constituent of the suspended load of modern rivers, up to 87 percent in one of the cases investigated. Among beach sands with exceptionally high content of fines Friedman (1967) quotes the case of the southwestern coast of Louisiana where, owing to the rapid supply of unsorted sediments from the Atchafalaya River, carried westward by long-shore currents, the waves are incapable of winnowing out the fine fraction. In general, however, it seems reasonable to state that the high percentage of the minus 62.5 microns fraction present in the sandstones underlying the Battle Member is suggestive of a river environment rather than of a nearshore milieu where the sorting action of waves would tend to remove the fines.

The stratigraphic sections investigated in southern Alberta clearly show (see Appendix B) that sediments tend to become finer toward the top (contact with Battle Member). The percentage of fine fraction increases upward and so does the phi value of the median of the coarse fraction (median becoming smaller), while the standard deviation of the coarse fraction decreases upward (sorting increases). This type of <u>internal organization</u> is also, according to Potter (1967), characteristic of the alluvial (fluviatile) environment, although not exclusive to it.

Shape of the Cumulative Curves

Cumulative curves of the sandstones of the Edmonton Formation have been constructed (see Appendix B) on arithmetic-probability paper in order to compare their general shape with the shape of curves studied

by Doeglas (1946 and 1950), Van Andel and Postma (1954), and Pryor (1960).

Three general types of cumulative curves can be identified for the sandstones of southern Alberta. They are (Fig. 6) type I or coarse type, type III fine, and a transitional type, II, that falls between the two extremes.

Doeglas (1946) showed that clastic sediments from different environments display three basic types of cumulative curves R, S, T, and any combination of the three. Type R curves originate under continuous current on stream beds of rivers, strong marine currents and surf action. S curves are originated by down-stream decreasing capacity and T curves are typical of stagnant water where the entire suspension is deposited. Combinations of R + S + T are typical of environments of running water with strongly fluctuating velocities (Doeglas, 1946, p. 33). Comparison of the curves of the Edmonton Formation with the basic types described by Doeglas (1946) shows that type I (Fig. 6) curves are more or less pure R-type curves with small contributions of S and T-type distributions. In type II and type III the relative importance of R decreases, and S and T-types have a greater influence on the shape of the curves.

Van Andel and Postma (1954) applied the same basic criterion to size-distribution of recent sediments of the Gulf of Paria. Five basic types of curves, three of which are similar to Doeglas' R, S, T types, were found to be present. Type F curves (more or less the R-types of Doeglas) were found to be typical of the upper delta environment where there is a predominance of the river regime. Type S clays and silts are characteristic of the lower delta and F + S-types occur where there is mixture of the two environments. Figure 7 shows the sand types of

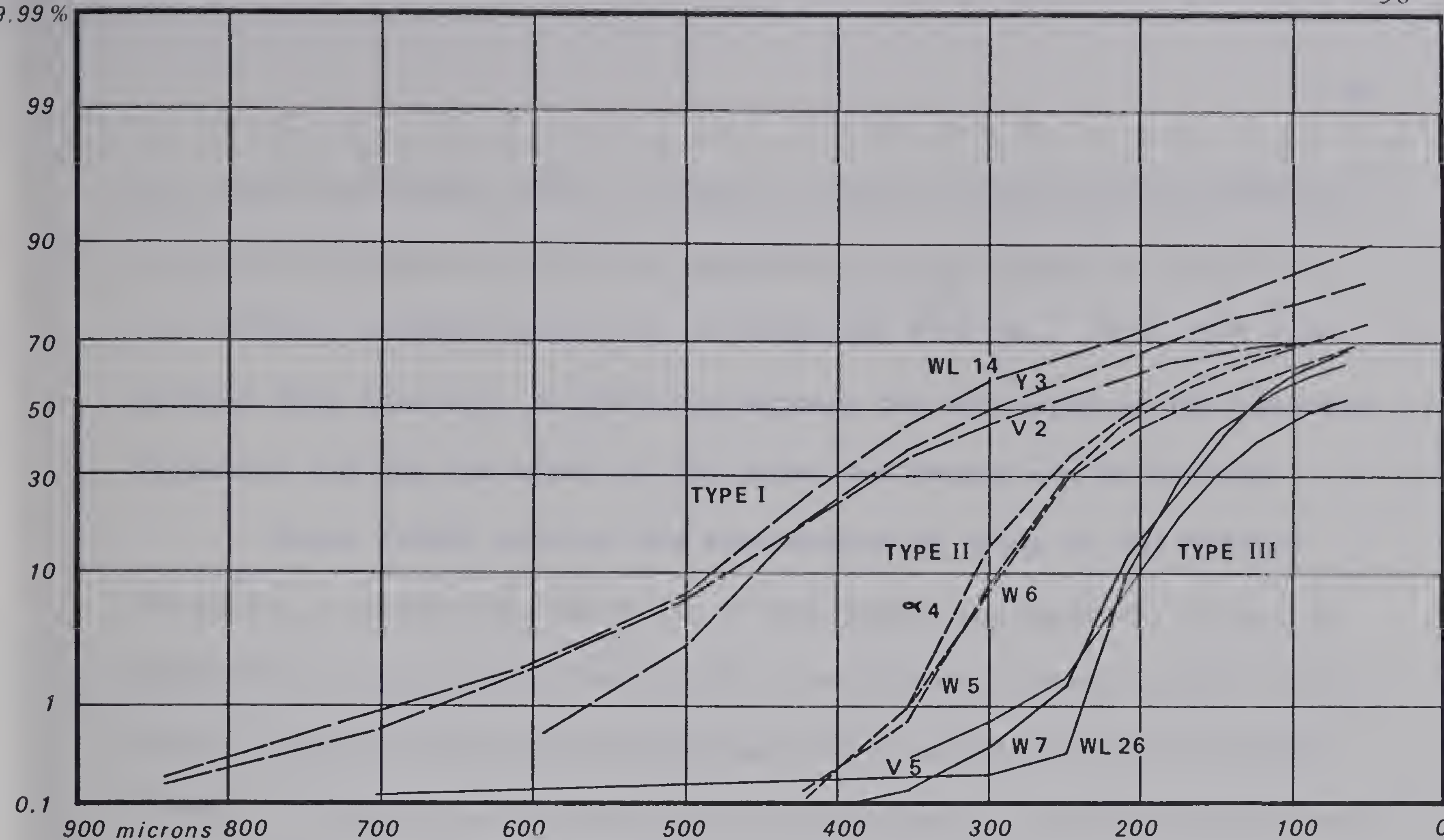


FIGURE 6

Types of grain-size curves of sandstones of the Edmonton Formation

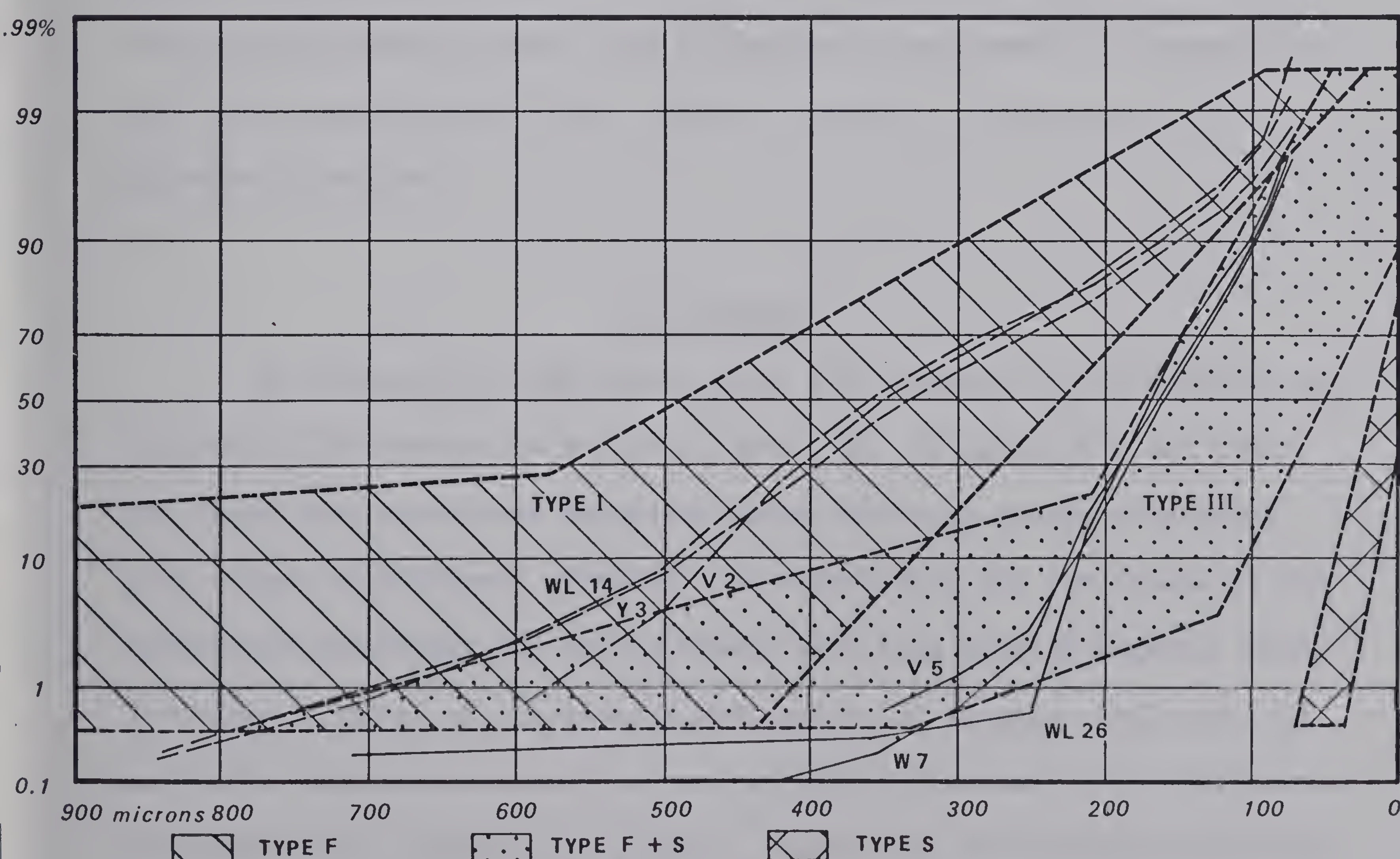


FIGURE 7

Comparison of grain-size curves of the Edmonton Formation with sand types F, F + S, and S of van Andel and Postma (1954)

Van Andel and Postma (1954). Curves of types I and III of the Edmonton Formation have been plotted for comparison in the fields of the F and F + S-types, without accounting for the fine fraction. Both with and without fine fraction, an affinity between the two types of the Edmonton Formation and the two types of Van Andel and Postma can be noticed.

Pryor (1960) applied the same method of study to the McNairy Formation, a Cretaceous sandstone of Tennessee and Kentucky. From the similarity of the cumulative curves of the McNairy Formation with curves of the F-type of Van Andel and Postma (1954) and the R-type of Doeglas (1950), a fluviatile environment was postulated for the Cretaceous sandstone.

Although this type of approach to grain-size analysis is not completely satisfactory in determining the depositional environment, it has to be noted at least that a fluviatile environment is compatible with the general shape of the cumulative curves of sandstones of the Edmonton Formation.

C-M Diagram

By plotting on logarithmic paper the diameter of the coarsest one percentile (C) versus the median diameter (M), Passega (1957 and 1964) has shown that sandstones deposited under different energy conditions give origin to different patterns. In Figure 8(A) the C-M values of the sandstones underlying the Battle Member have been plotted together with the basic patterns of the generalized diagram of Passega (1957, Fig. 12, p. 1973). Values from total curves including fines have been used here. The samples fit remarkably well basic patterns I, IV, and the lower part of pattern V, following the lower and medial part of the "boomerang" that

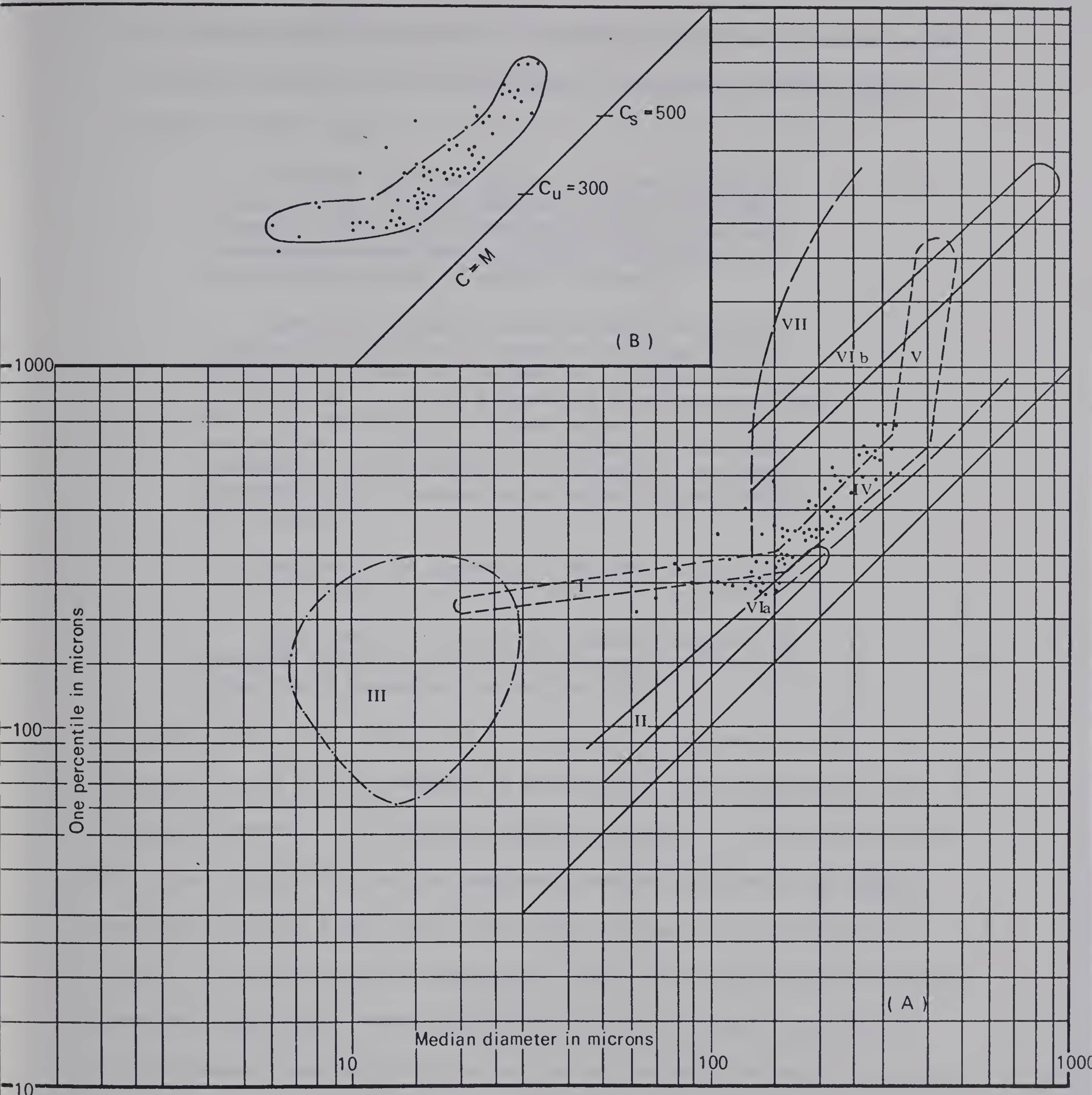


FIGURE 8

(A) C–M plot of sandstones of the Edmonton Formation in the basic patterns of Passega (1957)

I IV V – Rivers, tractive currents

II VIa VIb – Turbidity currents

III – Quiet water deposits

VII – Beaches

(B) C–M pattern of sandstones of the Edmonton Formation

is the characteristic expression of sediments deposited under the action of tractive currents. Of C-M patterns I, IV, and V, Passega (*ibid.*, p. 1973 and 1974) says:

> "Pattern I is the typical pattern formed by rivers and by tractive currents in areas of low velocity. Very fine particles settle, mixed with intermediate-size particles which are placed in suspension in areas of maximum velocity.
>
> Rivers or tractive currents which have beds composed of particles of sand of the same size as those concentrated at the bottom of the suspension form Pattern IV. This pattern is parallel with limit C=M. The maximum and minimum values of C in the pattern are an indication of maximum and minimum turbulence at the bottom of the current, provided material of all transportable sizes are available to the current.
>
> Pattern IV is generally continued on the fine side by Pattern I, on the coarse side by Pattern V.
>
> When rivers or tractive currents transport by traction sands too coarse to be supported in suspension, their deposits form Pattern V."

The inflection points that mark the boundaries between Pattern I and Pattern IV, and between Pattern IV and Pattern V are respectively the maximum diameter transported in uniform suspension in the upper part of the water column (Cu) and the maximum diameter transported in graded suspension in the lower part of the water column (Cs). The plot of samples collected from the Mississippi River (U.S. Waterways Experimental Station, 1939) shows that sands forming Pattern V come from the main channel where traction along the bottom is the basic mechanism of transport, whereas Pattern IV is typical of sediments from the subaqueous bank, and Pattern I is originated in protected backwaters.

In Figure 8(B) the C-M values of the sandstones of the Edmonton Formation have been contoured in order to show the distinct patterns.

Only a very few samples disagree with the "boomerang" shape of the plot identified on the basis of the maximum concentration of points. The anomalous points that fall outside the "boomerang" can easily be explained (Royse, 1968) as due either to energy fluctuations in the stream or to "mixing of environments" by faulty sampling.

The Cu (approximately 300 microns) and Cs (approximately 500 microns) values of the samples are in fairly good agreement with the Cu and Cs of the Mississippi River samples from Mayersville, Mississippi, and therefore similar energy conditions can be inferred for the depositional environment of the sandstones underlying the Battle Member.

The C-M approach to the detection of sedimentary environments is empirical and, when it first appeared in 1957, was based on a relatively small number of observations, made mostly on recent sediments. Since then, however, it has been applied by various authors in a number of studies of recent and ancient deposits, and the results have been extremely encouraging. The applications include intensive environmental studies of Tertiary sediments in Italy (Passega, 1964; Rizzini and Passega, 1964) carried out by the government-owned Italian Oil company (E.N.I.), the results of which are largely unpublished. Studies of modern sediments of the Adige River, Northern Italy, also confirm the usefulness of the C-M method (unpublished E.N.I. report quoted in Passega, 1964). In the published literature, the usefulness of C-M diagrams has been acknowledged by Weller (1960), Dodge (1965), Warner (1966) and Doeglas (1968). Bull (1962) has shown that by C-M patterns it is possible to differentiate mudflows, stream channels, braided streams, and "intermediate" environments in recent alluvial fans of Fresno County, California. Royse

(1968) substantiates the genetic interpretation of C-M diagrams and their validity for the recognition of fluviatile environments with examples from the Paleocene of North Dakota. Composite plots of one percentile versus median of the fluviatile Tongue River and Sentinal Butte Formations show patterns similar to the one exhibited by the sandstones of the Edmonton Formation. These composite patterns are explained as representing the combination of the several environments (channel, levee, flood-plain, and backswamp) of which the general fluviatile environment is composed.

To recapitulate, a strong indication of fluviatile origin emerges from the C-M patterns of the sandstones underlying the Battle Member. Different energy conditions that are typical of the general fluviatile environment are suggested by Patterns I, IV, and V. Of the three Patterns I and IV are the best represented and only few samples seem to reflect energy conditions typical of the main channels of streams (channel fill). Most of the samples belong to the graded suspension type that is more characteristic of channel or point bar deposits which are confined to channel or channel-proximal positions. Samples that reflect conditions typical of floodplains (Pattern I) are generally abundant toward the top of the sampled sections, near the contact with the Battle Member.

Plot of Two Statistical Parameters

The use of combinations of textural parameters for the discrimination of different sedimentary environments has been discussed by several authors. Mason and Folk (1958) were successful in distinguishing sands of beach, coastal dune, and eolian flat environment from Mustang Island

by means of plots of skewness versus kurtosis. Friedman (1961) showed that dune and beach sands can be distinguished by plotting mean grain size versus skewness, that "within limitations, river sands can be distinguished from beach sands on the basis of plots of the third moment (skewness) against standard deviation (sorting)" (ibid., p. 524), and that a plot of standard deviation versus mean grain size delineates three fields, one for river sands, one for dune sands and one of overlap. Sahu (1964) devised a more elaborate plot of several statistical parameters to discriminate among the various possible environments of deposition of sands. The best possible separation is obtained, according to Sahu, by a plot of mean phi deviation ($\sqrt{\sigma_1^{-2}}$) against the ratio of standard deviation of kurtosis to standard deviation of mean size time standard deviation of variance of all samples ($\frac{S_{K\sigma}}{S_{Mz}} \cdot S(\sigma_1^2)$).

A simple and effective way of separating modern dune, beach and river sands was derived by Moiola and Weiser (1968) from the method originally described by Friedman (1961). By plotting various statistical parameters of 120 sands from known recent environments, they showed that a plot of mean diameter versus standard deviation defines a clear separation of beach and river sands along a straight line. Since the standard deviation is a measure of sorting of the sediments, what Moiola and Weiser's diagram means is: (a) river sands can have mean diameters smaller than beach sands, (b) in the range of the mean diameters that can be common to both environments, river sands tend to be less sorted (higher standard deviation) than beach sands. This is in effect a different way of expressing the relationships that Doeglas (1968) shows by means of the Q_1 Md Q_3 indices (see next section). The separation of the river and beach

environments is better defined when the grain size is measured in quarter phi units, but it is possible to distinguish the two fields even at the whole phi level.

The application of this method to the sandstones underlying the Battle Member plus two sandstones immediately above it, and three from the Whitemud Formation of the Cypress Hills is illustrated in Figure 9. The line of separation between beach and river sands was taken from Moiola and Weiser's (1968, p. 50, Fig. 6A) quarter phi diagram, since the grain size of the sand fractions of the samples was analyzed in quarter phi units.

Before discussing the results, a few observations on the methods have to be made if the comparison is to be meaningful.

The statistical parameters used for the Alberta samples refer to the plus 62.5 microns (4 phi) fractions only, that is approximately 50 to 85 percent of the total sample for each sample, whereas Moiola and Weiser analyzed total samples by sieve and pipette analysis. Statistical parameters of partial samples were used to eliminate the possibility of introducing a bias derived from diagenetically formed clay. It must be noted that if total samples were used, the mean diameter would be smaller (higher phi), the standard deviation larger, and the whole plot would look "more fluviatile". For a check, the mean and standard deviation of samples WL11, 13, 14, 15, 16, 17, and 18, that are among the samples with higher mean in Figure 9, have been recalculated to include the fines. As a result, their position on the diagram of Figure 9 was shifted toward the upper right hand corner, that is toward "river".

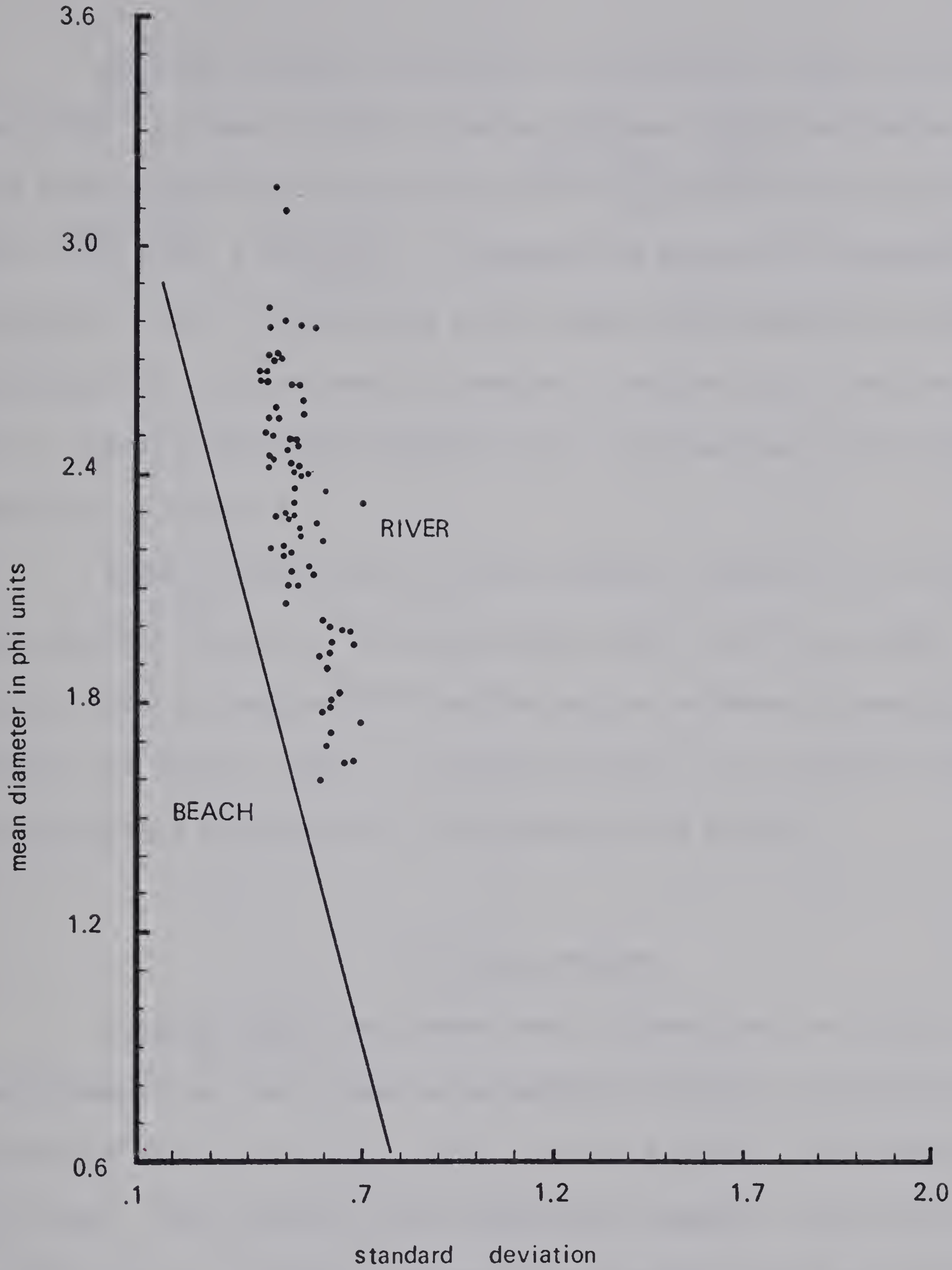


FIGURE 9

Plot of mean diameter versus standard deviation of sandstones of the Middle Edmonton Formation in the diagram of Moiola and Weiser (1968)

Mean and standard deviation of the Alberta sands are calculated according to Inman's (1952) formulas whereas Moiola and Weiser use Folk and Ward's (1957) mean grain size $(\frac{\Phi 16 + \Phi 50 + \Phi 84}{3})$ and standard deviation $(\frac{\Phi 84 - \Phi 16}{4} + \frac{\Phi 95 - \Phi 5}{6.6})$. Although the two sets of parameters differ slightly, after recalculating a few means and standard deviations according to Folk and Ward's formulae, I noticed that they never differed by a quantity that would sensibly alter the position of the samples in the plot of Figure 9.

Figure 9 shows that all the analyzed samples lie to the right of the straight line that separates beach sands from river sands. The fit of the Alberta samples with the fluviatile sediments investigated by Moiola and Weiser (1968) is therefore perfect, and one more indication of fluviatile environment is obtained by this method.

Q_1 Md Q_3 Indices

Doeglas (1968) has shown that a discrimination of the sedimentary environments by grain size can be achieved through the plotting of the Φ values of first quartile Q_1 (25%), median Md (50%), and third quartile Q_3 (75%). This method is very simple and somewhat crude, but the plot of 874 samples of recent sediments from various environments from different parts of the world shows that certain parameter values are exclusive to some particular milieu.

Figure 10 reproduced from Doeglas (1968) is the grouping of the 874 samples according to the indices Q_1 Md Q_3 whose values have been rounded to the next higher integer Φ unit. Some sedimentary environments can already be distinguished on the basis of the three indices Q_1 Md Q_3.

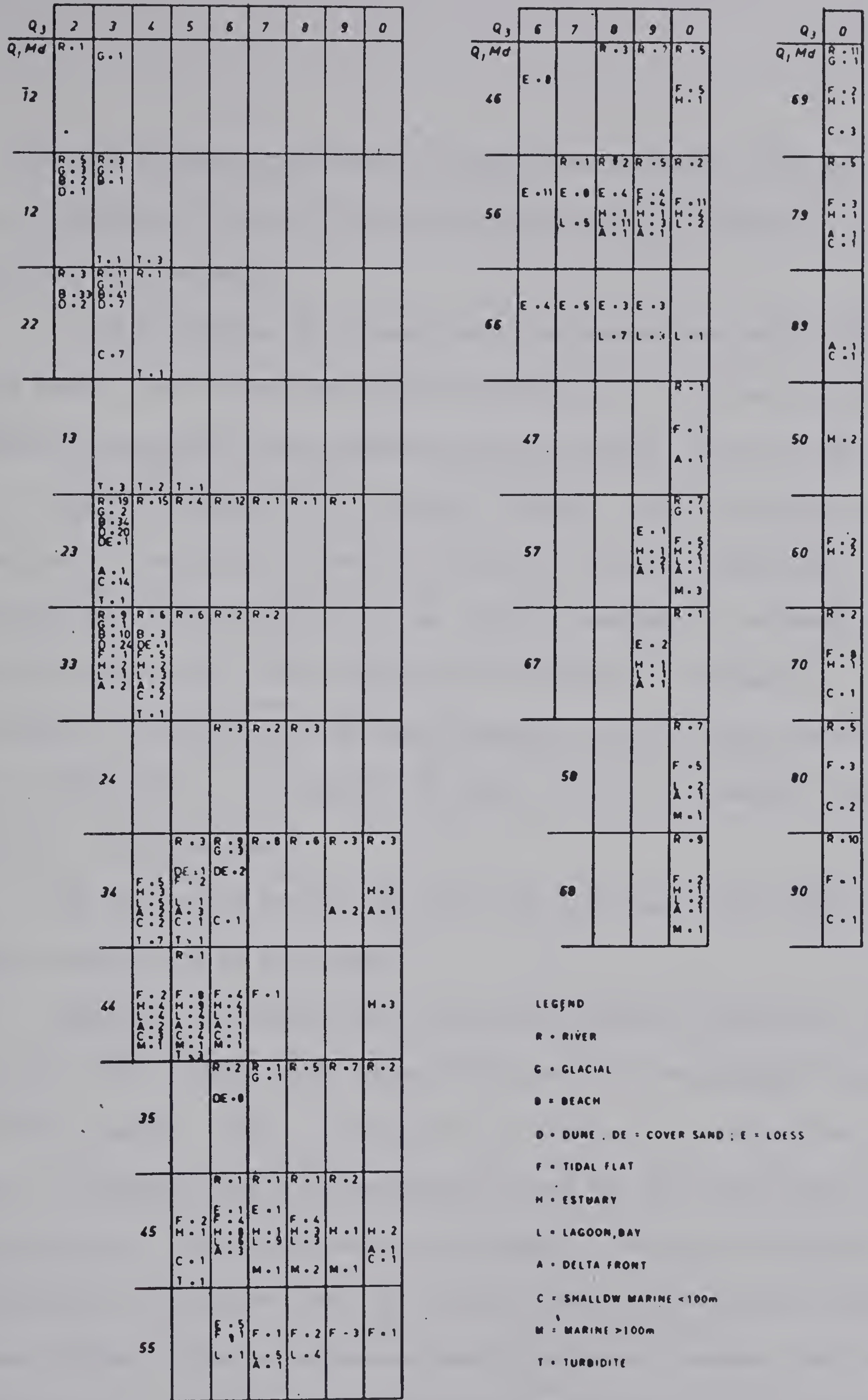


FIGURE 10

Distribution of Q_1, MdQ_3 indices in sedimentary environments (from Doeglas, 1968)

When the same indices are common to several environments, the application of two additional indices, the one-percentile and the ninety-nine-percentile are necessary.

Q_1 Md Q_3 indices of 73 samples of the sandstones underlying the Battle Member, and of two sandstones overlying it, have been calculated, grouped in categories, and compared with the results given in Figure 10.

For the application of Doeglas' method, total percentages, recalculated to include the minus 4 Φ fraction are used here since they are certainly more representative of the original sediments, although somewhat distorted by the fact that some of the clay is authigenic. Since the minus 4 Φ fraction has not been analyzed, in the cases in which the plus 4 Φ fraction is less than 75 percent of the total sample, the notation >4 will be used.

Let us examine one by one the Q_1 Md Q_3 classes into which the Alberta samples can be subdivided.

<u>Class 223</u> (9 samples from the Middle Edmonton Formation: WL10, WL11, WL12, WL13, WL14, WL15, WL16, WL17, and Y3. One sample from above the Battle Member: E22). In the plot of Figure 10, in which the two digits on the left hand side represent Q_1 and Md, and the figures at the top represent Q_3, this index-class is common to several environments and a definition can be given only by the two additional 1 percent and 99 percent indices. Marine sediments seem to be more abundant than continental ones. Sands from the fluviatile environment can, however, fall in this class.

<u>Class 224</u> (1 sample: α20). This class is very poorly represented in Doeglas' plot: only one river sample and one turbidite.

<u>Class 22>4</u> (1 sample: V2). This class does not have any representation in Figure 10.

Class 233 (2 samples: L3 and WL24). Class 233 is one in which many sedimentary environments are represented. River and dune sands are common here together with sands from other continental environments, but the largest group is the beach sands. Shallow marine sands are also common.

Class 234 (8 samples: L4, L5, WL18, W2, W3, W4, Y4, Y7). Fifteen samples, all from rivers belong in this class in Figure 10.

Class 23>4 (12 samples: B3, L7, U10, V1, V3, W5, W6, α4, α7, α14, α15, α18). In Doeglas' table, classes 235, 236, 238, 239 are represented exclusively by river sands.

Class 334 (5 samples from the Middle Edmonton Formation: W1, WL20, WL21, WL22, WL23, E24. One sample from above the Battle Member: E24). Class 334 shows samples from several depositionary environments. Rivers as well as tidal flats, beaches, lagoons, and delta fronts are common in this class in Figure 5. For further discrimination of the samples, as for samples from classes 223 and 233, five digits are necessary.

Class 33>4 (20 samples: A17, A19, B1, B2, E5, N2, N5, I2, U4, U9, U11, W7, W8, Y7, WL25, WL26, WL27, α5, α8, α16). Classes 335, 336, and 337 in Figure 10 are represented exclusively by river sediments.

Class 34>4 (12 samples: A18, D1, D7, E7, N3, N4, I1, V4, V5, WL19, α9, α10). In Figure 10 samples from several environments have indices 345 and 346. Rivers are well represented in these two classes. The next two higher classes 347 and 348 are exclusively of river sediments.

Class 3>4>4 (1 sample: E8). River sediments are abundant in the 355-350 classes of Figure 10, the other large group of samples being cover sands.

Class 44>4 (1 sample: U5). Generally tidal flats, estuaries, lagoonal and shallow marine silty sands fall in these classes.

Class 4>4>4 (1 sample: D2). River silts are present in these classes.

Fifty-five percent of the 73 samples from the sandstones and silty sandstones underlying the Battle Member have indices that belong to classes in which only river sediments appear in the plot of Figure 10. Eighteen percent belong in classes in which river samples outnumber samples from all other environments by a ratio of 2 to 1. Only twenty-five percent of the samples have indices that are common to beaches as well as to rivers and mixed environments. Sixteen percent of the samples have indices that are generally more common for beaches than for rivers. The sum of the data would therefore overwhelmingly indicate general fluviatile conditions for the sandstones underlying the Battle Member. Doeglas (1968, p. 99) states:

> "Series of samples from an environment will give more definite determinations. In such series a number of data may not be distinctive; others however will be characteristic for the environment. A series of river sediments may contain 122, 223, 233, which might indicate beach, dune or coastal deposits; when the series continues with 234, 236, 336, 248, all exclusive indications for a fluvial environment, it is more probable that the entire series belongs to river deposits."

This situation is encountered in the samples analyzed. 223, 233, 334 indices are especially abundant in the lower part of the Wizard Lake section where the well sorted sandstones have probably been deposited

in a river channel whose energy conditions cannot be distinguished from the ones found on beaches by means of quartile indices. The samples of the higher part of the section near the Battle Member, however, show unmistakable fluviatile characteristics by their 33>4 indices.

Sandstones from all the sampling localities show undoubted fluviatile characters when compared with the results of Doeglas (1968).

Three samples from a section of the Whitemud Formation near Eastend, Saskatchewan, gave Q_1, Md, Q_3 indices 334 (H34 and H36) and 333 (H35). These indices cannot be considered diagnostic since sediments from various environments belong in the 333 and 334 classes of Doeglas.

Factor Analysis

A multivariate statistical technique aiming at the objective analysis of sands by comparing the entire grain-size distribution of each sample of a population has been described by Klovan (1966). By means of the Q-factor analysis it is possible to obtain a clear discrimination of sediments deposited under different energy conditions.

The analytical technique of the Q-factor analysis is rather complex and will not be dealt with in detail here. Detailed explanations can be found in Klovan (1966), Imbrie and Purdy (1962), Imbrie and Van Andel (1964). The description of the computer program (main routine FACTO) used in this study is given by Klovan (1968). The description of subroutines CORE, EIGEN, TRACE, LOAD, VARMX, used in the analysis can be found in Klovan (*ibid.*) and in the IBM Scientific Subroutines Package Book. The computer language in which the program is written is Fortran IV, and the computer used is an IBM 360/40 of the Roan Selection Trust Data Processing Centre in Ndola, Zambia.

In brief, the technique consists of considering each grain-size distribution of a population of samples as a vector in a space having as many dimensions as the number of classes (quarter phi intervals) in which the distribution is expressed. The position of each vector in this space is determined by the amount of sediment in each class. Every vector is then compared with every other vector and the degree of proportional similarity between two vectors is defined as cos-Θ. A table, the cos-Θ matrix, expressing the degree of similarity of each vector to every other vector, is obtained. This table of coefficients is analyzed by factor analysis. The problem is to find factors, or factors axes, that would account for most of the information contained in the cos-Θ matrix in decreasing order of importance (eigen-values of the cos-Θ matrix), and to rotate the factor axes so that the sample vectors can be projected onto the axes. These projections (factor loadings) are expressed by numbers whose numerical values are an indication of how much a sample is "influenced" by each factor.

Klovan (1966) has shown that recent sands from Barataria Bay, Louisiana, previously studied by Krumbein and Aberdeen (1937) can be subdivided by Q-mode factor analysis into three natural groups on the basis of their degree of dependence upon three factors that can be considered as end-members of a triangular distribution in which all the samples can be fitted. In the specific instance of the Barataria Bay samples the three factors correspond to three different types of energy responsible for the deposition of the sands in the area, viz. wind-wave action on the beaches, current action in the channels, gravitational settling in quiet sheltered lagoons.

Owing to the size of the computer, the Q-mode factor analysis of the sandstones of the Edmonton Formation was carried out on seventy samples. The analysis was limited to the plus 4 phi (62.5 microns) fractions for which a subdivision into eighteen quarter phi classes was available. The complete table of the frequency distribution of the coarse fraction of the samples is given in Appendix B.

The Q-mode factor analysis of the distributions shows (Table IV) that the first four eigenvalues, or factors, explain 95.6 percent of the information, and of these, the first three account for 92.4 percent of it.

TABLE IV

Eigenvalues and Cumulative Percentages for the Sandstones of the Middle Member of the Edmonton Formation

	Eigenvalues	Cumulative Percentage of Eigenvalues
1.	39.05075	55.787
2.	19.70549	83.937
3.	5.94815	92.435
4.	2.21842	95.604
5.	0.90113	96.891
6.	0.72475	97.927
7.	0.59608	98.778
8.	0.40369	99.355
9.	0.31584	99.806
10.	0.07666	99.916

The factor loadings of the seventy samples were then calculated for the first four factors, and their matrix, rotated according to varimax procedure (Klovan, 1966), is given in Table V.

In order to transform the information contained in Table V into a usable form, each loading was squared to give the factor component, and each squared element was then divided by the correspondent communality (first column of Table V) according to the procedure suggested by Klovan (1966). This procedure normalizes the data and expresses, in percentage, the "influence" of each factor on each grain-size distribution.

It was immediately evident that, of the four factors, the first three were essential to describe the samples and that the fourth factor could then be neglected. Only four of the seventy samples were "influenced" by the fourth factor by more than ten percent, viz. D2 (49%), U5 (45%), WL19 (27%), and N4 (12%). These samples were then eliminated from the list. Their grain-size distribution curves (Fig. 11) look somewhat anomalous and heterogeneous and it is quite likely that they are due to analytical error or faulty sampling. All the other samples were then recalculated in order to redistribute the percentage of "influence" of the fourth factor proportionally among the first three (factors A, B, and C). Thus were obtained the percentages of Table VI in which the amounts subtracted from the fourth factor (D) are also given.

Having thus reduced the factors to three, the information can be plotted on the triangular diagram of Figure 12 where factors A, B, and C are the apices of the triangle and all the samples are plotted according to the degree of "influence" of each factor.

TABLE V

Factor Loadings

Sample No.	Communalities	Rotated factor matrix (4 factors)			
		Factor A (55.8%)	Factor B (28.1%)	Factor C (8.5%)	Factor D (3.2%)
WL10	0.98268	0.00414	0.90590	0.39278	0.08786
WL11	0.89113	0.10138	0.89182	0.12833	0.26276
WL12	0.99649	0.00229	0.85681	0.50980	0.04967
WL13	0.99616	0.03313	0.94965	0.30053	0.05381
WL14	0.95271	0.08117	0.95411	0.06321	0.17829
WL15	0.99653	0.07557	0.95671	0.27331	0.02859
WL16	0.98333	0.07181	0.98735	0.00352	0.05727
WL17	0.93635	0.13974	0.92990	0.12594	0.19036
WL18	0.97455	0.53955	0.40073	0.70823	0.14574
WL19	0.91218	0.81756	0.05422	0.00326	0.49073
WL20	0.99372	0.87146	0.02623	0.45713	0.15691
WL21	0.98811	0.95087	0.01495	0.28540	0.04763
WL22	0.98260	0.63760	0.06500	0.70893	0.26316
WL23	0.99310	0.09431	0.01564	0.41577	0.04709
WL24	0.97987	0.03665	0.72340	0.65262	0.17115
WL25	0.98449	0.81228	0.03290	0.51895	0.23299
WL26	0.94769	0.96199	0.02269	0.13577	0.05758
WL27	0.97395	0.71593	0.03723	0.67409	0.07479
W1	0.97753	0.40811	0.14254	0.87228	0.17258
W2	0.96135	0.09720	0.47350	0.83625	0.16846
W3	0.98677	0.32845	0.22825	0.90878	0.03003
W4	0.98880	0.20460	0.44087	0.86260	0.09212
W5	0.98502	0.26736	0.23006	0.92745	0.02077
W6	0.97682	0.22983	0.23377	0.93199	0.02695
W7	0.98538	0.96756	0.04453	0.17460	0.12932
W13	0.99048	0.40209	0.18094	0.88481	0.11477
V1	0.94817	0.04989	0.88097	0.36592	0.18884
V2	0.95598	0.05817	0.95266	0.03182	0.20980
V3	0.94813	0.06606	0.82925	0.49413	0.10923
V4	0.99584	0.83460	0.07391	0.53943	0.05404
V5	0.97312	0.95593	0.03324	0.11507	0.21203
D1	0.99244	0.95609	0.10121	0.10393	0.23933

Table V (continued)

Sample No.	Communalities	Rotated factor matrix (4 factors)			
		Factor A (55.8%)	Factor B (28.1%)	Factor C (8.5%)	Factor D (3.2%)
D2	0.78839	0.56055	0.26424	0.14323	0.61954
D7	0.92248	0.90643	0.09332	0.09722	0.28757
Y3	0.98277	0.04928	0.97559	0.10488	0.13254
Y4	0.99721	0.21491	0.89188	0.39433	0.00834
Y6	0.98715	0.23092	0.31669	0.91203	0.04154
Y7	0.96873	0.91221	0.00510	0.34136	0.14154
α4	0.98802	0.16141	0.33984	0.91839	0.05507
α5	0.98460	0.54735	0.30797	0.75242	0.15497
α7	0.94285	0.27559	0.46290	0.77070	0.24215
α8	0.53047	0.64238	0.02983	0.34134	0.02010
α9	0.97940	0.97202	0.04672	0.12715	0.12738
α10	0.99861	0.97558	0.05987	0.18079	0.10286
α14	0.97765	0.01461	0.84745	0.48643	0.15049
α15	0.95376	0.09844	0.41435	0.87235	0.10671
α16	0.98276	0.65675	0.09384	0.72271	0.14254
α18	0.98377	0.08839	0.75446	0.60857	0.19072
α20	0.89884	0.13678	0.92077	0.14188	0.11032
A17	0.96489	0.59422	0.06506	0.76206	0.16374
A18	0.99670	0.92038	0.02202	0.38466	0.03387
A19	0.94480	0.88493	0.02814	0.38543	0.11115
E5	0.96479	0.88182	0.02736	0.38819	0.18903
E7	0.97737	0.96807	0.02480	0.19607	0.03385
E8	0.90744	0.94055	0.02069	0.12979	0.07437
E22	0.97302	0.05127	0.85959	0.47423	0.08113
E23	0.94581	0.04709	0.91837	0.30240	0.09345
E24	0.95992	0.55541	0.07324	0.78310	0.18119
L3	0.98390	0.08493	0.37040	0.91237	0.08398
L4	0.99566	0.30158	0.33878	0.90884	0.09001
L5	0.99062	0.24877	0.26151	0.92716	0.02679
L7	0.94525	0.38422	0.12828	0.87399	0.13153
N2	0.97021	0.63366	0.04626	0.70889	0.25299
N3	0.96918	0.97059	0.02744	0.15228	0.05638

Table V (continued)

Sample No.	Communalities	Rotated factor matrix (4 factors) Factor A (55.8%)	Factor B (28.1%)	Factor C (8.5%)	Factor D (3.2%)
N4	0.95711	0.91115	0.10005	0.00292	0.34276
N5	0.93264	0.84593	0.00272	0.39095	0.25335
U4	0.96488	0.90766	0.00272	0.33105	0.17727
U5	0.60836	0.52965	0.21511	0.07773	0.52489
U9	0.99799	0.65793	0.12678	0.73674	0.07903
U10	0.96353	0.25089	0.16747	0.92622	0.12103

TABLE VI

Influence of Factors A,B,C on Each Sample (in Percent)

Sample No.	Factor A	Factor B	Factor C	Amount subtracted from Factor D
WL10	0	84	16	1
WL11	1	97	2	8
WL12	0	74	26	0
WL13	0	91	9	0
WL14	1	99	0	3
WL15	1	92	7	0
WL16	1	99	0	0
WL17	2	96	2	4
WL18	31	16	53	2
WL20	78	0	22	3
WL21	92	0	8	0
WL22	45	0	55	7
WL23	82	0	18	0
WL24	0	55	45	3
WL25	71	0	29	6
WL26	98	0	2	0
WL27	53	0	47	0
W1	18	2	80	3
W2	1	24	75	3

Table VI (continued)

Sample No.	Factor A	Factor B	Factor C	Amount subtracted from Factor D
W3	11	5	84	0
W4	4	20	76	1
W5	7	6	87	0
W6	5	6	89	0
W7	97	0	3	2
W13	17	3	80	1
V1	0	85	15	4
V2	0	100	0	5
V3	0	74	26	1
V4	70	1	29	0
V5	99	0	1	5
D1	98	1	1	6
D7	98	1	1	9
Y3	0	99	1	2
Y4	4	80	16	0
Y6	6	10	84	0
Y7	88	0	12	2
α4	3	12	85	0
α5	31	10	59	2
α7	9	24	67	6
α8	78	0	22	0
α9	98	0	2	2
α10	97	0	3	1
α14	0	75	25	2
α15	1	18	81	1
α16	45	1	54	2
α18	1	60	39	4
α20	2	96	2	1
A17	38	0	62	3
A18	85	0	15	0
A19	84	0	16	1
E5	83	0	17	3
E7	96	0	4	0

Table VI (continued)

Sample No.	Factor A	Factor B	Factor C	Amount subtracted from Factor D
E8	98	0	2	1
E22	0	77	23	1
E23	0	90	10	1
E24	33	1	66	3
L3	1	14	85	0
L4	9	5	86	1
L5	6	7	87	0
L7	16	2	82	2
N2	44	0	56	7
N3	97	0	3	0
N5	83	0	17	7
U4	89	0	11	3
U9	43	2	55	1
U10	7	3	90	1
Samples not utilized because of high D factor				
WL19	73	0	0	27
D2	40	9	2	49
N4	87	1	0	12
U5	46	8	1	45

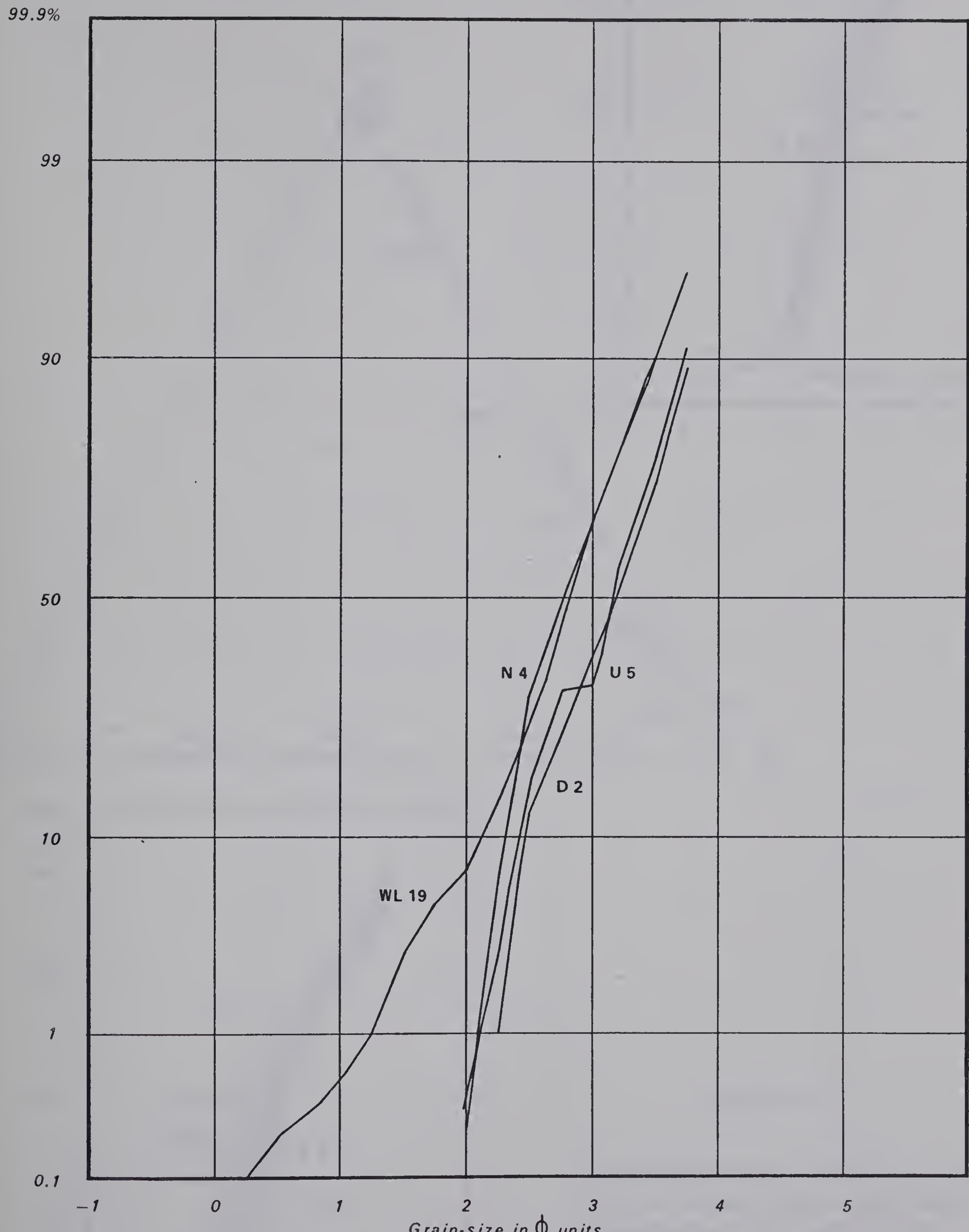
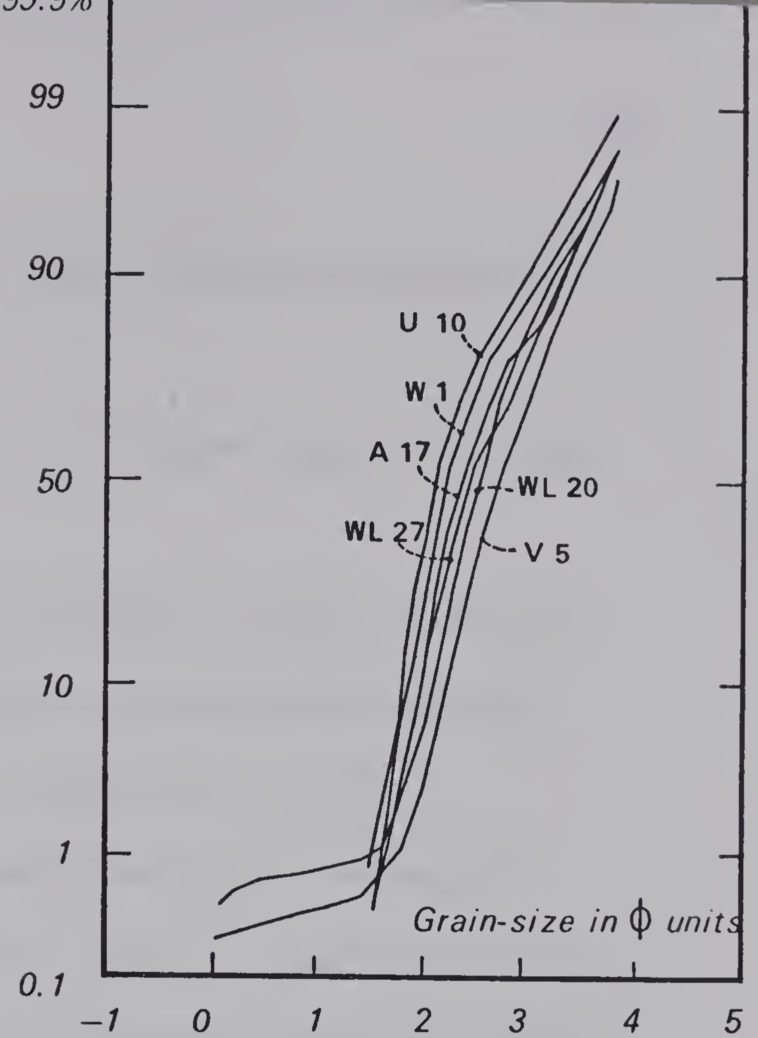
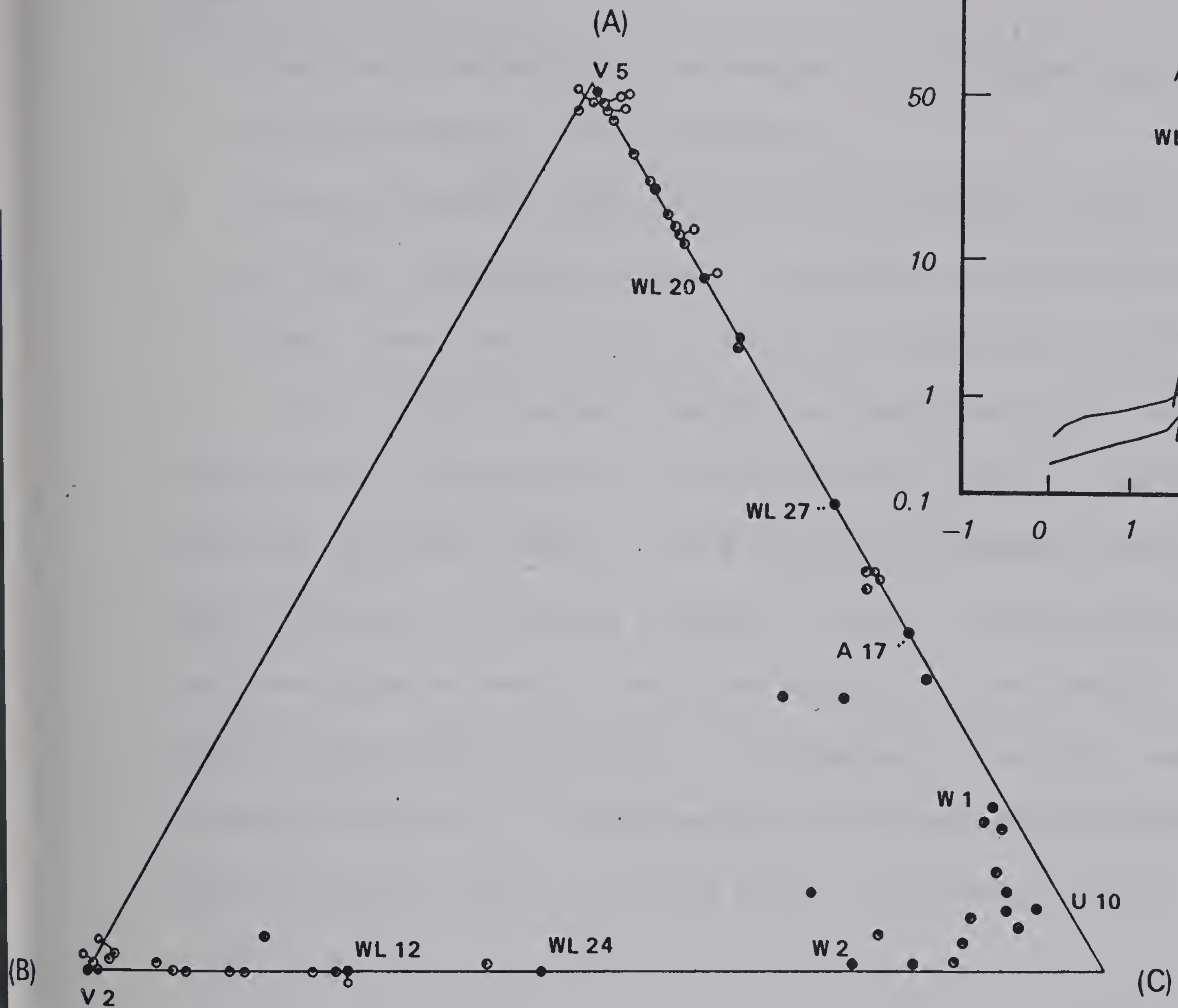


FIGURE 11

Curves of samples in which 4th factor is >10%





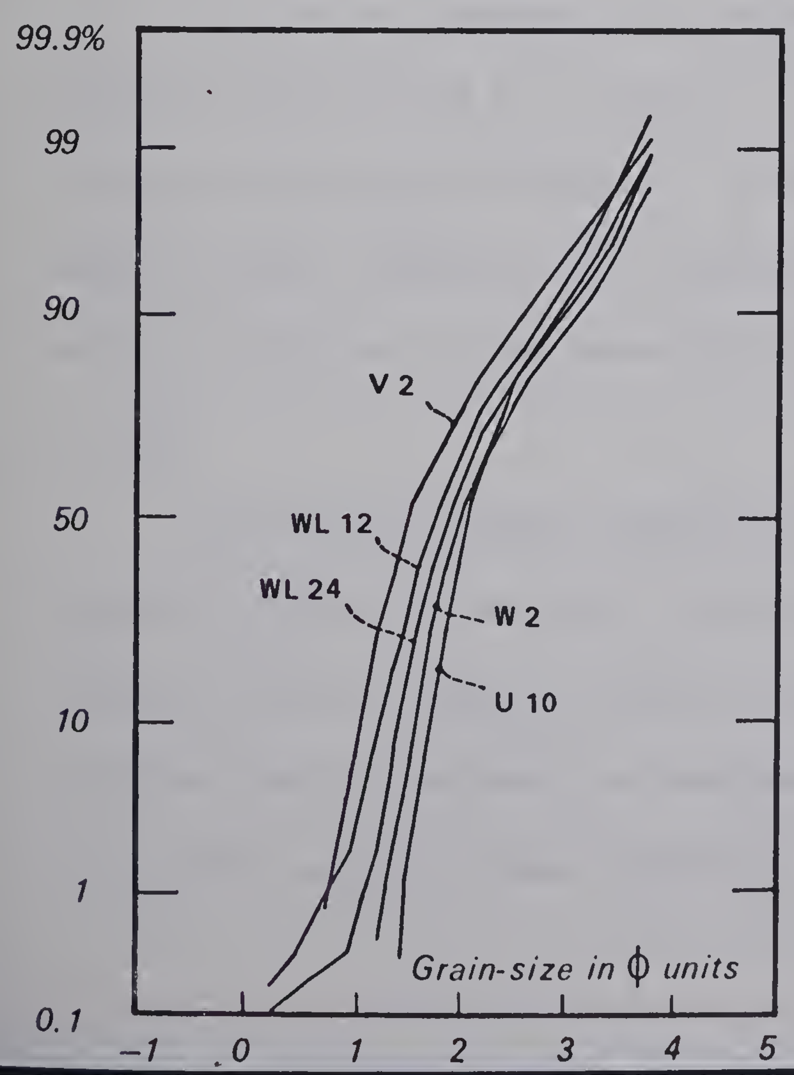


FIGURE 12

Q–mode factor analysis of sandstones of the Edmonton Formation, and cumulative curves of samples from A to C and from B to C

The following characteristics are evident from the diagram of Figure 12.

1. There is a tendency for the samples to be grouped along the sides and in proximity to the end-members.
2. There are samples along the A-C and B-C sides, but none along the A-B side, indicating mixing of conditions represented by factors A and C and B and C, but no mixing of conditions A and B.

To a certain extent, the picture portrayed by the triangular diagram of the sandstones of the Edmonton Formation is analogous to the one shown by Klovan (1966). The Barataria Bay samples are also grouped along the sides, indicating a mixing of pairs of energy-types, but not the three types of energy conditions together in one sample. In the Barataria Bay samples also two of the factors do not mix, namely there is no mixing of factor III representing surf energy conditions and factor II representing gravitation settling energy conditions (Klovan, 1966, Fig. 2, p. 119, and Fig. 6, p. 123).

If we now examine the cumulative curves of the plus 62.5 microns fractions going from A to C and C to B (Fig. 12), we notice a gradual increase in grain size toward B. This increase in coarseness of the sediments is also reflected in a decrease in the amount of the minus 62.5 microns fractions in the same directions (47% in V5, 34% in U10, 28% in V2).

The environmental significance of factors A, B, and C will be discussed in detail in the next section where the results of the Q-factor analysis will be compared with the results of the other methods. So far, with the factor analysis, we can subdivide the samples into three groups, A, B, and C and two mixed subgroups A-C and B-C. We can also deduce from

the cumulative curves of Figure 12 that factor B suggests an environment of higher competency of the transporting medium than C, and higher competency of C than A.

Comparison of Methods and Results

Some of the methods of interpretation of the depositional environment from the grain-size distribution applied in this study are empirical. They are based on comparison of certain statistical parameters of a distribution from an unknown environment with analogous parameters of distributions from known environments. They are all based on factual observations of recent sediments. Most are based on the selection of two or more statistical parameters, be they the quartiles as in Doeglas (1968), the mean and standard deviation as in Moiola and Weiser (1968), or the one percentile and median as in Passega (1957). The whole-curve approaches of Doeglas (1946) and Van Andel and Postma (1954) are independent of any particular statistical parameter in as much as the shape of the total curve is taken into account. In this respect they have something in common with the Q-mode factor analysis of Klovan (1966), although they lack the rigour and the mathematical elegance of the latter method. The Q-mode factor analysis of a group of samples from an unknown environment cannot tell us what the environment was, but it can subdivide the samples into natural groups, perhaps better than any other technique. It is conceivable that the Q-mode factor analysis of a population might separate groups consisting of samples deposited under similar energy conditions and in similar environments. The evaluation of this possibility is, however, beyond the scope of this study since it would require the investigation of a large number of

sediments from different environments processed by the same technique. What it was proposed to achieve through a Q-mode factor analysis of sandstones of the Edmonton Formation, was a test of some of the empirical methods against the more rigorous analytical technique.

For this purpose, in Figure 13 the results of the Q-mode factor analysis are compared with the results obtained by simple examination of the shape of the cumulative curve and with the C-M diagram. Figure 13 shows in (b) the plot of the samples that fall within the 80 percent line of each end-member; in (c) the three families of curves from Figure 6; and in (a), the C-M diagram of the samples plotted in (b), using the same symbols. Curves of the types I, II, and IIIof (c) correspond to samples that plot very near the respective end-members B, C, and A of the triangular distribution (b) of the Q-mode factor analysis. Samples that lie within the 80 percent lines of each end-member A, B, and C fall respectively in patterns I, V, and IV of the C-M diagram of (a).

A correlation between the results of the Q-mode factor analysis and the shape of the cumulative curve was to be expected because in fact the Q-mode factor analysis is just a mathematical way of looking at the curve as a whole. The correlation between C-M diagram and factor analysis on the other hand shows that the first percentile and the median diameter are extremely critical parameters of a grain-size distribution.

The C-M diagram utilizes only parameters of the coarse half of the distribution, but in the case of the Alberta samples, these parameters have been calculated from total distribution curves, that is including the minus 62.5 microns fraction, whereas the Q-mode factor analysis was carried out on the coarse (sand) fractions only; that is, the plus 62.5 microns fraction calculated as one hundred percent. Since the two methods

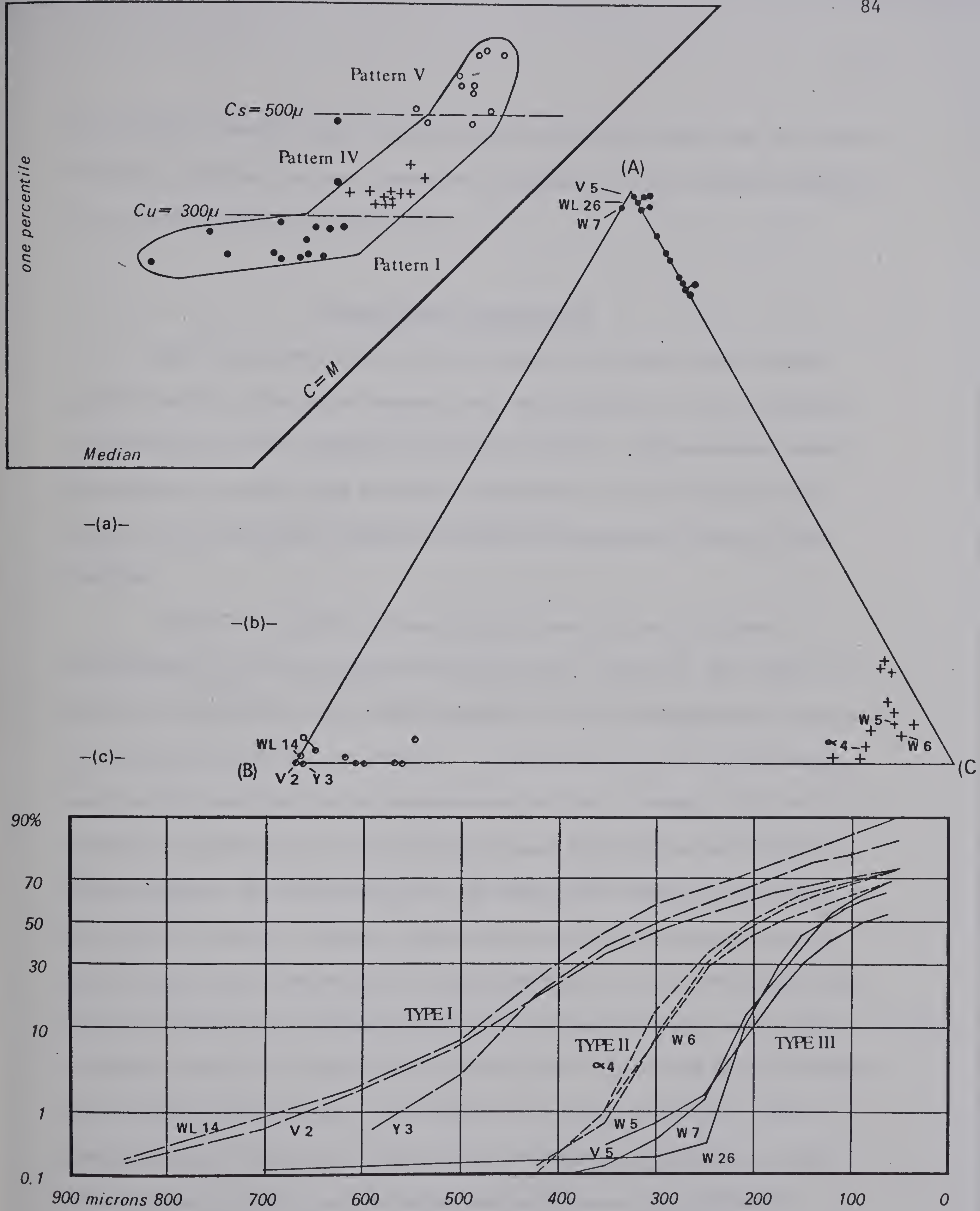


FIGURE 13

Comparison of C–M diagram (a), Q–mode factor analysis (b), and cumulative curves (c) of sandstones of the Edmonton Formation

give similar results (Fig. 13 (a) and (b)), one must infer that the coarse fraction contains the most important information on the energy conditions of the environment of deposition.

Depositional Environment

All the methods that have been applied in this study indicate quite clearly a fluviatile depositional environment for the sandstones underlying the Battle Member in southern Alberta. The agreement among the results obtained from different approaches is nearly perfect and there is no indication of marine nearshore environment in any of the samples.

Within the general fluviatile environment three main sub-environments can be recognized from the general shape of the cumulative curves, the pattern of the C-M diagram, and the grouping of the samples in the multivariate factor analysis. Conditions of fast-flowing water, such as the ones that can be encountered in river channels, are indicated mostly in the lower part of the section away from the contact with the Battle Member, and particularly in the subsurface samples from Wizard Lake (WL10 to WL17). Energy conditions typical of floodplains and of quiet waters, with deposition of large amounts of fine material are more characteristic of the higher part of the section and they were a prelude to the extensive swampy to lacustrine conditions under which the dark claystones of the Battle Member were to be deposited. Energy conditions intermediate between these two, and probably reflecting deposition in other river subenvironments such as bars, are very common throughout the

section as indicated by the large number of samples falling in C-M pattern IV of Figure 8.

The lack of pebble-size material and the abundance of fines suggests rather slow-flowing rivers, a location relatively far away from any mountains and a generally gentle relief in the Upper Cretaceous landscape. The areal extent over which these fluviatile conditions have been detected indicates that the river system, or systems, was covering a large area and channels and floodplains must have been present at the same time over a large extension of territory. Conditions of this type are encountered today on the landward side of large deltas.

As to the provenance and direction of transport of the sediments, this study alone cannot provide an answer. The sections that have been sampled are too few and too far apart to determine provenance and direction of transport in such a complex fluviatile system. One of the main characteristics of the fluviatile environment is the lateral shifting of specific subenvironments in time. Directional studies in the sandstones of the whole of the Edmonton Formation would be highly desirable but they should be carried out in small areas and in great detail. Furthermore, the scarcity of sedimentary structures in the whole of the Edmonton Formation makes the problem a complex one. The present study indicates, however, that textural characteristics can be used to unravel the Upper Cretaceous paleogeography of southern Alberta, and it is felt that detailed grain-size analyses are perhaps the best approach to the problem of provenance and direction of transport.

CHAPTER FIVE - CLAY MINERALS

Seven samples of the Battle Member, two of the Battle Formation and twenty-seven samples of sandstones, claystones and siltstones underlying the Battle in the Alberta Plains and in the Cypress Hills were analyzed for their clay mineral content by the X-ray diffraction method.

A few samples were also treated by differential thermal analysis by the Department of Soil Science, University of Alberta.

TECHNIQUE

Oriented glass-slide mounts for X-ray diffraction analysis of the clay fraction of samples of claystone, siltstone and sandstone were prepared as follows.

1. Samples of 20 to 30 grams each were soaked for 24 to 48 hours in 150 ml of distilled water with 0.5 grams of sodium hexametaphosphate dispersant (Calgon). Further dispersion was obtained by agitating the slurry for approximately 2 minutes in a rotary blender.
2. The slurry, diluted to 1000 ml with distilled water, was allowed to settle for 4 hours and 15 minutes in a sedimentation cylinder.
3. Fifty ml samples of suspension containing clay particles with diameter smaller than 2 microns were siphoned by pipette from a depth of 5 cm below the surface (Folk, 1961) and allowed to settle on a frosted glass slide placed at the bottom of a beaker.

4. After 22 to 24 hours the liquid was siphoned out taking care not to disturb the material that had already settled. The slide was then allowed to dry at room temperature.

A Philips Norelco Type 12045 B/3 X-ray diffractometer with a Geiger counter, using nickel-filtered Cu K-alpha radiations operated at 35 KV and 15 MA, was used for the study of all samples. Various settings of the scalar-meter ratio were employed in order to obtain the best possible resolution for each sample. Diffractograms were recorded on a Brown strip-chart running at a speed of one half inch per minute.

After a first run, the slides were treated with ethylene glycol and run again for detection of expandable clays. Finally they were heated in an oven at 550°-600° C for 4 hours (Keller, 1962) and analyzed again.

Diffractograms of the region between $2\Theta = 4$ and $2\Theta = 20$ (22 Å to 4.4 Å) were usually run for the basal spacing, but other angles were also scanned when necessary.

CLAY MINERALS DETECTED BY X-RAY DIFFRACTION

A brief discussion of the clay minerals detected by X-ray diffraction in samples of the Battle and the underlying sandstones and fine-grained sediments, and of the criteria for their identification, is given in the following paragraphs. A record of the relative abundance of each clay mineral detected is given in Tables VII and VIII. The stratigraphic position of the samples is shown in Figure 16.

The theoretical principles involved in the study of clay minerals by X-ray diffractometry will not be discussed here. They are outlined in a number of books and articles (Grim, 1968; Millot, 1964; and Weaver, 1958).

TABLE VII

Clay Minerals of the Battle Member and Underlying Sediments of the Alberta Plains

Samples	Clay Mineral (D = dominant; S = strong, M = moderate; sl = slight, t = trace			
	Montmorillonite	Kaolinite	Hydrous Mica (and Mica)	Chlorite
Battle M.				
WL40	D	M	-	-
WL34	D	M	-	-
U31	D	t	-	t
U25	D	sl	-	-
A28	D	M	-	-
A22	D	S	-	t
A20	D	M	-	-
Sandstones				
WL25	D	sl	-	-
WL20	D	M	-	-
WL15	D	S	-	-
WL10	D	S	-	-
WL2	D	sl	-	-
U12	D	sl	t	t
U10	D	sl	t	-
U5	D	sl	t	sl
A21	D	M	t	-
A19	D	M	-	-
A13	D	sl	sl	sl
A2	D	sl	-	t
Siltstones, claystones, and shales				
WL30	D	M	sl	-
WL9	D	sl	sl	-
WL8	D	-	-	t
U17	D	M	sl	t
U2	D	sl	M	t
A12	D	M	S	-
A1	D	sl	sl	t

TABLE VIII

Clay Minerals of the Battle and Whitemud Formations of the Cypress Hills (Quarry 45)

Samples	Clay Mineral (D = dominant; S = strong; M = moderate; sl = slight; t = trace)			
	Montmorillonite	Kaolinite	Hydrous Mica (and Mica)	Chlorite
Battle Fm.				
S5	D	-	-	-
S13	D	M	-	-
Whitemud Fm. Sandstones				
S17	-	D	M	-
S33	S	M	S	-
Whitemud Fm. Siltstones, Claystones, and shales				
S20	-	S	D	-
S21	D	S	M	t
S23	-	S	S	-
S27	D	S	M	-
S30	-	S	D	-
S38	sl	S	D	sl

Minerals of the 12-15 Å Group

The largest peaks occur in the 12-14 Å region of the diffractograms for nearly all the untreated samples. These peaks are generally broad and their position cannot be defined precisely. Upon glycolation (Figs. 14 and 15) they shift to a 16-17 Å position, and upon heating, to a 9-10 Å position. This type of behaviour identifies clay minerals of the montmorillonite group s.l. or smectite of British authors (Warshaw and Roy, 1961). Montmorillonite peaks should move upon glycolation to a 17 Å position. If the position of the peak is not 17 Å, but indicates a smaller basal spacing, the clay mineral is of the mixed layer type. Weaver (1956, p. 206) published a curve showing the relationship between the shift of the "glycolated" peak and the percentage of expandable layers (montmorillonite) in the mixed-layer clay. From this curve, it can be calculated that the montmorillonite of two-thirds of the Alberta samples is a mixed-layer clay with 80 to 90 percent of expandable layers. Since, upon heating, the peaks move to a 9-10 Å position, the other component of the mixed layer clay must be illite. Since the peaks do not move completely to a 10 Å position, but stay between 9.3 and 9.7, the mixed layers should, according to Weaver (ibid.), contain some chlorite. The montmorillonite peaks of Figure 14 (a) and Figure 15 (a) and (c) should then represent rather pure montmorillonite (expanding to 17.0), whereas Figure 14 (b) (peak expanding to 16.8) should represent a mixed-layer clay mineral composed of approximately 90 percent expandable layers and 10 percent non-expandable layers, largely illite, with possibly some chlorite.

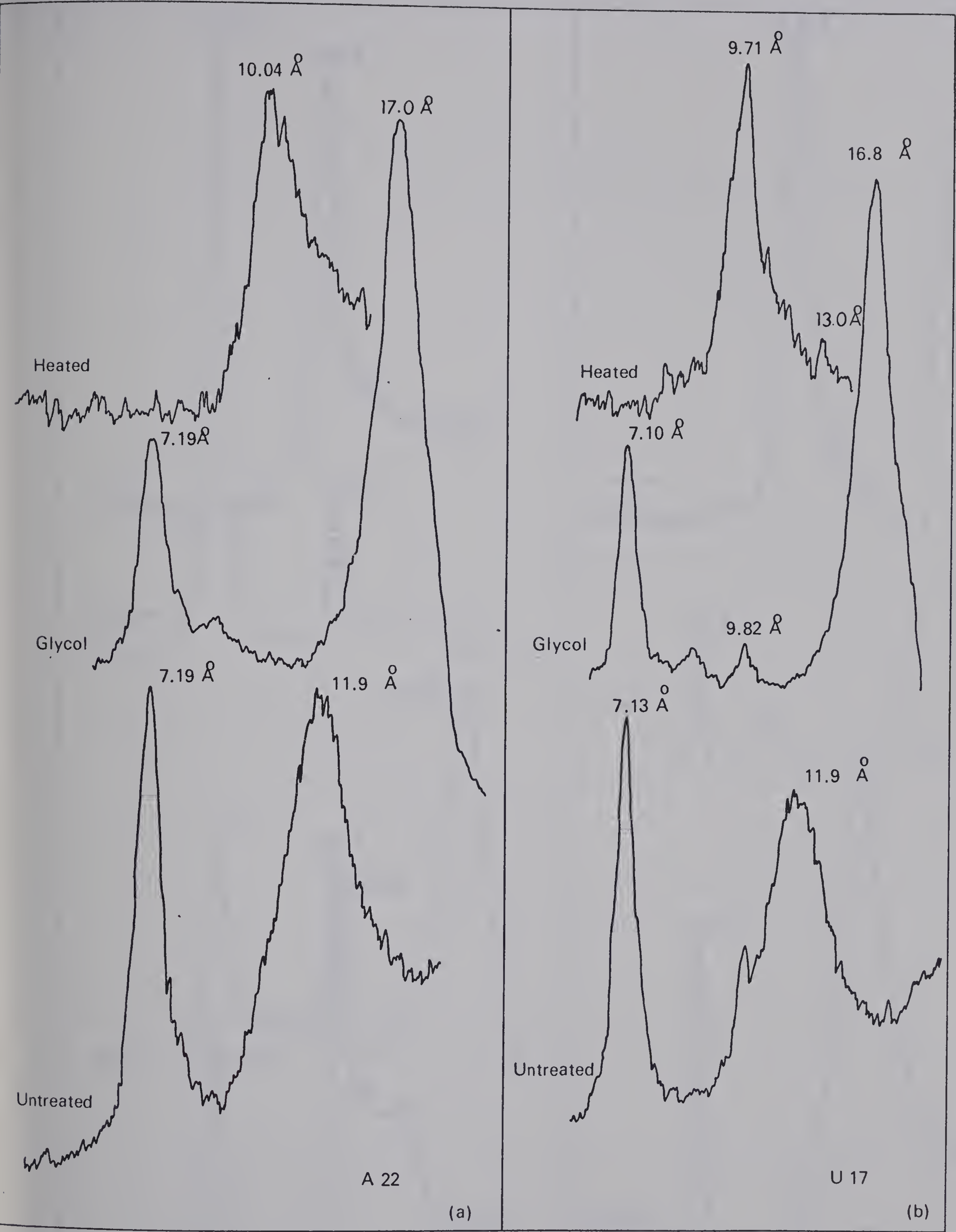


FIGURE 14. Diffractograms of clay fractions:
(a): Battle Member of the Edmonton Formation
(b): olive-grey claystone underlying the Battle Member

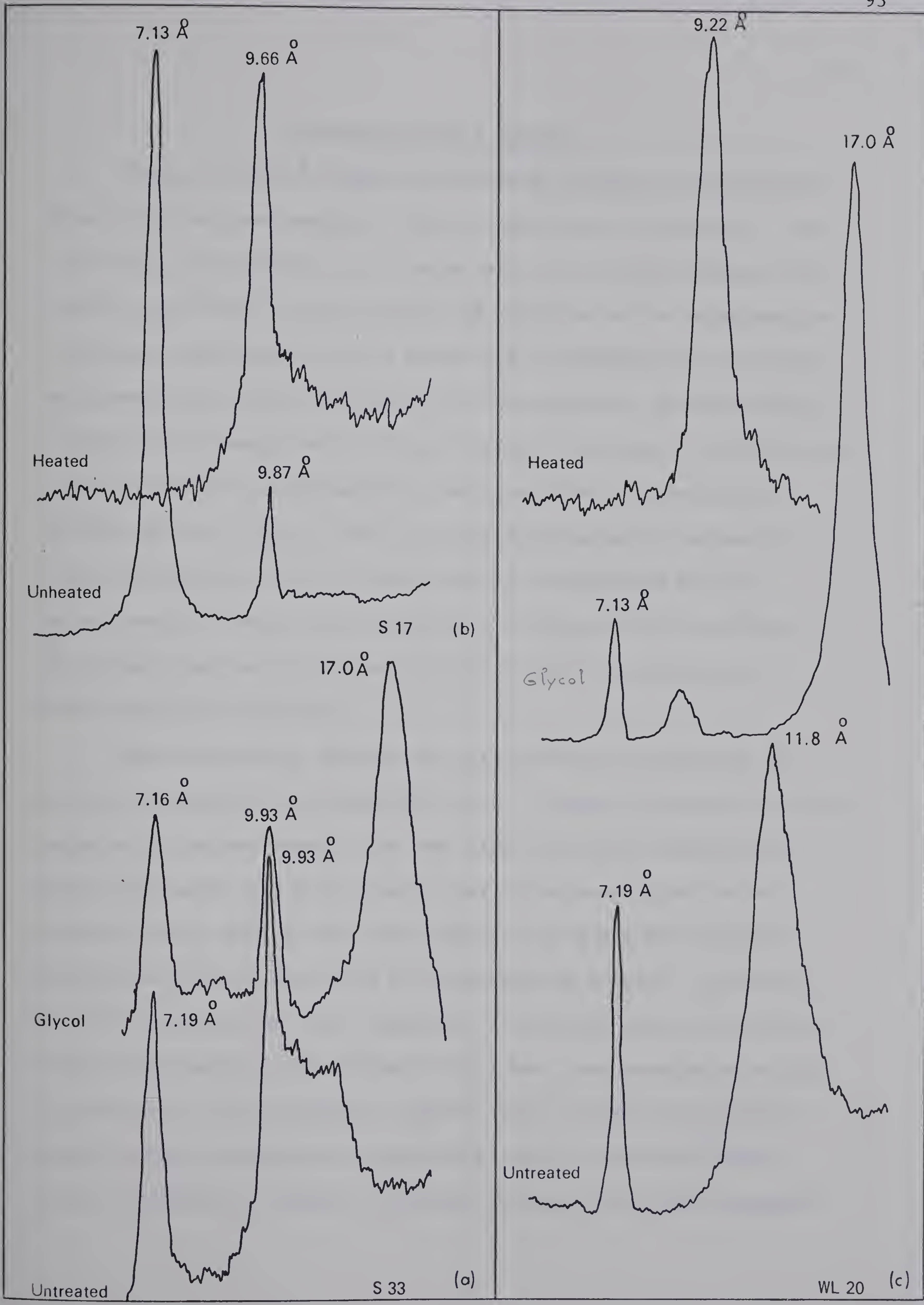


FIGURE 15. Diffractograms of clay fractions of sandstones:
(a) and (b): Whitemud Formation; (c): Edmonton Formation

Minerals of the 7 Å Group

Peaks in the 7 Å region are extremely frequent in the diffractograms of the analyzed samples. They are attributed to kaolinite. Upon glycolation, these peaks do not change position, and they disappear upon heating at 550°-600° C. The presence of kaolinite in the sandstones and siltstones underlying the Battle Member and in specimens from the Whitemud Formation has also been detected in thin section. The fact that the 7 Å peaks are generally sharp and well defined (see Figs. 14 and 15) also indicates that we are dealing with kaolinite rather than halloysite (Warshaw and Roy, 1961, p. 1481), and the dehydroxylation temperature shows that it is not dickite (dehydroxylation temperature 650° C). Narrow, sharp 7 Å peaks, such as the ones of Figure 14 (a) and Figure 15 (b) have also been interpreted by Keller (1962) as indicative of well-crystallized kaolinite.

Small amounts of chlorite are very difficult to detect in the presence of kaolinite and montmorillonite. A number of methods have been suggested by various authors, but none seems completely satisfactory. First order peaks of chlorite would occur in the same region as the montmorillonite peaks in untreated samples, but they would not move upon glycolation and they would be accentuated by heating. In some of the diffractograms there is a suggestion of a slight peak in the 13-14 Å region after heating. These (Fig. 14 (b)) have been interpreted as due to chlorite in "trace" amounts. However, the 7 Å peaks are certainly almost entirely attributable to kaolinite, rather than being second order reflections of chlorite. Chlorite is indeed rare in the examined

thin sections and, moreover, the diffractograms in the region of the higher order reflections reveal peaks at 1.48-1.49 Å that are typical of kaolinite (Warshaw and Roy, 1961).

Minerals of the 10 Å Group

Peaks in the 10 Å region (Fig. 15 (a) and (b)) indicate minerals of the Illite (hydrous mica)-Muscovite group. The peaks are affected neither by glycolation nor by heating.

As to the exact identification of the mineral, additional information can, according to Weaver (1958), be obtained by a close examination of the diffractogram. Fine grained, poorly developed illites will give relatively broad peaks, whereas muscovites show narrow and sharp peaks. In the analyzed samples, it may be assumed that the sharp and narrow peaks exhibited by the sandstones of the Whitemud Formation (Fig. 15 (a) and (b)) are due to fine grained, clay-size muscovite. An abundance of muscovite was also noticed in the microscopic examination of the coarse fraction. Broad, low, arched, or poorly defined 10 Å peaks such as the 9.82 Å peak of the diffractogram of the glycolated samples of Figure 14 (b), could possibly be attributed to illite.

SEMI-QUANTITATIVE ESTIMATION OF CLAY MINERALS

A number of methods for the determination of the percentages of the clay minerals present in the clay fraction of a mudstone have been proposed by various authors, among them, Johns *et al.* (1954), Weaver

(1958), Oinuma and Kobayashi (1960), Pelzer (1966). Such determinations involve the measurement of peak areas, the use of standard reference samples, and the application of ratios in order to convert the intensities of the diffractogram into percentages of clay minerals present.

In order to obtain accurate measurements, however, the clay minerals have to be relatively clean and well defined, they have to compare closely with the chosen standards, they have to be of constant chemical composition and the ratio of mixing has to be constant in the mixed-layer clays.

Keller (1962) in the study of the clay minerals of a mudstone that resembles very closely the Battle, has shown that the degree of weathering also produces a bias in the quantitative measurements. In pairs of samples taken a few inches apart, and differing only in degree of weathering, the intensity of the montmorillonite peak was remarkably different; higher in the fresh sample in some pairs, higher in the weathered one in others.

Pierce and Siegel (1969), calculating the percentages of clay minerals in some recent marine muds according to five different published methods, have found that the results are significantly different. They attribute the differences to factors inherent in the minerals and not to the methods which are all sound in a theoretical sense.

The samples studied in the present work, and especially the ones from the Battle Member and the Battle Formation have all been subjected to some surface weathering.

Considering the above-mentioned factors, a very rough estimate of the relative abundance of the clay minerals was preferred to a

rigorous quantitative approach. Terms such as "dominant", "strong", "moderate", "slight", and "trace", are used, as in Keller (1962) instead of numerical values. "Dominant" is used when a clay mineral is predominant in the assemblage, generally constituting more than one half or two thirds of the clay fraction, "trace" when it is barely perceptible and the other terms to express amounts between the two extremes. For the determination of the approximate quantity present, a visual estimation of the peak areas was used, and ratios given by Weaver (1958, p. 270) were applied.

Warning must be given that, as pointed out by Gibbs (1965, 1968) the settling technique used for the preparation of the slides, tends to accentuate the peaks of montmorillonite relatively to the peaks of kaolinite. This is due to differential settling that segregates the fine grained montmorillonite on the very top of the preparation.

DISCUSSION OF THE RESULTS

Occurrence and Relative Abundance of Clay Minerals

In Tables VII and VIII are recorded the occurrence and the relative abundance of the clay minerals detected by X-ray diffractometry in the sediments of the Edmonton and of the Battle and Whitemud Formations (Fig. 16).

Montmorillonite is the predominant clay mineral in most of the samples; it is more abundant and frequent in the samples from the Alberta Plains than in the ones from the Cypress Hills as already pointed out by Irish (in Irish and Havard, 1968), but it is certainly present in the section at Quarry 45, both in the Battle and in the Whitemud Formation.

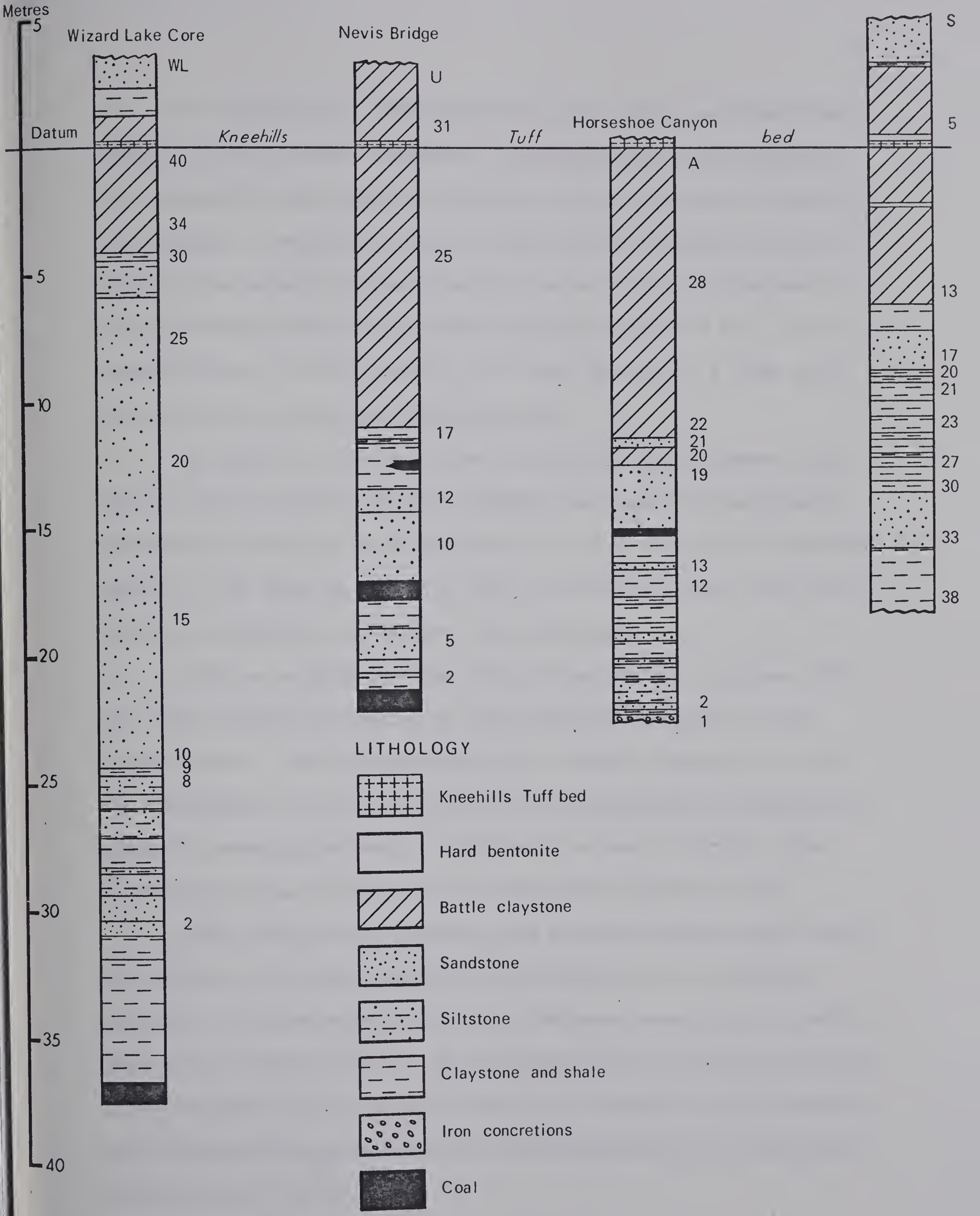


FIGURE 16

Stratigraphic columns showing the lithology of the samples analyzed for clay minerals.

In a recent study (Byers, 1969) kaolinite is the only clay mineral mentioned from the Whitemud Formation. Although certainly more abundant and economically more important, kaolinite is not the sole clay type in the Whitemud. A mixed-layer clay in which 80 to 90 percent is an expandable clay mineral (montmorillonite) has been found as "dominant" in two grey-brown claystones of the Whitemud (S21 and S27 of Fig. 16), and montmorillonite is also abundant in the fine fraction of a light grey silty sandstone of the same formation (S33).

In addition to the well known occurrences in the Cypress Hills, where it gives origin to economic deposits, kaolinite is also present, although subordinate to montmorillonite, in all but one of the twenty-six samples of the Edmonton Formation, both in the Battle Member and in the underlying sandstones, siltstones, and claystones.

Only two samples from the Battle Formation of the Cypress Hills have been analyzed as compared to seven from its equivalent of the Alberta Plains. The clay assemblages are, however, comparable in the two stratigraphic units, being made up of montmorillonite (dominant) and kaolinite (generally moderate, occasionally strong or slight). Some samples show traces of chlorite, but none shows any hydrous mica.

Mica, muscovite and sericite, and possibly hydromuscovite rather than illite, can be very abundant in the sediments of the Whitemud, whereas it is seldom encountered in the sediments underlying the Battle Member in the Alberta Plains. It is generally rare in the clay fraction of the sandstones and it is more frequent and abundant in the claystones and siltstones where some of the low and broad peaks can be interpreted as indicative of illite.

To summarize, this study shows: a great abundance of montmorillonite in most samples, the occurrence of some kaolinite in nearly all the samples of the Battle, the absence of hydrous mica from the latter, the abundance of montmorillonite in some claystones of the Whitemud, and finally, the relatively higher abundance of fine-grained mica in the Whitemud Formation than in the Edmonton equivalent.

Clay Minerals and Depositional Environment

Although the recognition of the depositional environment from the clay assemblages of sedimentary rocks has been the aim of many investigations, it is perhaps indicative of the degree of success of these investigations that one of the world's authorities on clays states that clay minerals can only be used to this end in conjunction with other studies, and that their value as environmental indicators is indeed much lower than fossils, sedimentary textures and structures, and certain other minerals (Millot, 1964, p. 434-435).

From the excellent reviews that Millot (*ibid.*) and Grim (1968) give of the literature, it is evident that the presence of particular clay types in sedimentary rocks depend upon a number of factors. Detrital inheritance, transformations, and neoformations, all play an important role in determining the end product. It is not easy to unravel the respective importance of each of these factors when we are faced with a clay assemblage that is the result of their interplay during three different processes and times in the history of the sediments: soil-formation (weathering), sedimentation, and diagenesis.

A number of authors feel that transformations during sedimentation, and perhaps early diagenesis, are the most important factor in determining the clay assemblage. In support of this view are the investigations conducted by Nelson (1960) on the sediments of the Rappahannock River, Grim et al. (1949) on the clays of the Gulf of California and off the Pacific Coast, and the survey by Rateev (1957). From the evidence produced by these authors it appears that kaolinite is generally found in a fresh-water environment and that it is transformed into illite in the marine milieu. Although there is certainly more than a suggestion of transformation in all of these papers, differential settling has also been suggested as a possible explanation for the decrease of kaolinite and increase of illite from the rivers to the open sea. Millot (1964, chapter X) points out that degraded clays such as montmorillonite are more stable in a fresh-water environment than in sea water where the abundance of K and Mg ions would tend to produce more stable complexes. Kaolinite, stable in fresh-water provided that the water is not undersaturated in silica, would also tend under saline conditions to transform to illite. It is significant that kaolinite is generally not abundant in saline and desert playa-type lakes where alkalis and alkaline earths are usually abundant.

If transformations do occur, the detrital inheritance is also important. Thus illite was found by Cuthbert (1944) to be the predominant clay mineral in the bottom sediments of Lake Erie, and kaolinite and montmorillonite have been found in large amounts in several marine sediments. The abundance of kaolinite in the Atlantic Ocean off the

west coast of Africa is probably indicative of the detrital transport from the continent (Millot, op. cit.)

From what has been discussed above, it is clear that it is only in conjunction with paleontological and sedimentological data that the clay minerals of the Edmonton Formation and of its Cypress Hills equivalents can be interpreted. A suggestion of fresh-water environment for the Battle can be found in the abundance of montmorillonite and kaolinite, and in the absence of illite. Another piece of negative evidence is the absence of glauconite, a typically marine mineral, from all the analyzed samples.

The uniformity of the clay mineral assemblage in the Battle from the Plains to Cypress Hills, together with the uniformity in other sedimentological and micropaleontological characters discussed in other parts of this study, would suggest uniformity in detrital inheritance and in sedimentary, as well as diagenetic environment. The abundance of montmorillonite can be explained by the synsedimentary to early diagenetic transformation of volcanic ash and detritus, as already pointed out by several authors.

The abundance of montmorillonite in the sediments underlying the Battle in the Plains, as opposed to the abundance of kaolinite in the Whitemud, can possibly be explained as due to a combination of detrital inheritance and neoformation. The sediments of the Edmonton Formation are rich in volcanic rock fragments, whereas those of the Whitemud (Byers, 1969) are generally richer in metamorphic lithic elements. Mellon (1960) has shown that in Lower Cretaceous rocks of Alberta, authigenic kaolinite is the clay mineral of the sands low in volcanic

detritus, whereas montmorillonite, chlorite, and kaolinite are the authigenic clays of the sands rich in volcanic fragments. It is also possible to speculate that, besides the authigenic component, a detrital montmorillonitic clay was released from the source area that provided the volcanic rock fragments of the Edmonton Formation, and a more kaolinitic clay from the source that provided the metamorphic rock fragments of the Whitemud.

CHAPTER SIX - SIDERITE

A number of siderite concretions, spherulites, and single crystals were found in the sandstones, siltstones, and claystones of the Edmonton and Whitemud Formations and in the ironstones of the Edmonton.

The possibility of using siderite as an environmental indicator was suggested in a paper by Weber _et al_. (1964) relating to the C^{13}/C^{12} isotopic ratio of siderite nodules in a cyclothem succession of Pennsylvanian age. There, the authors found that the δC^{13} values of nodules associated with marine fossils were positive, whereas nodules associated with fresh-water fossils yielded negative δC^{13} values. This is due to the fact that carbonate precipitation in fresh water is controlled by a dissolved bicarbonate which is generally richer in biogenic "light" carbon dioxide than in the marine environment where the bicarbonate dissolved in the water is essentially in isotopic equilibrium with the carbon dioxide of the atmosphere.

Thus, in order to gain some additional evidence on the depositional environment of the Whitemud Formation and of the sediments underlying the Battle Member in Alberta, a few samples of spherulites and nodules were submitted to Dr. P. Fritz for analysis. More samples from the Lower, Middle and Upper Edmonton Formation were successively collected in the Horseshoe Canyon and Drumheller areas, and analyzed. The whole complex subject of stable isotopes studies will not be treated here; only that which concerns the origin and depositional environment of the siderites.

OCCURRENCE AND ORIGIN OF THE SIDERITE

Whitemud Formation

In the type-section (Kupsch, 1956) of Dempster's Clay Pit, Eastend, siderite occurs in the upper member of the Whitemud Formation in the following different ways.

1. As honey-colored, idiomorphic, prismatic crystals, 0.3 to 0.7 mm long and up to 0.2 mm in diameter, occasionally twinned, scattered in the kaolinitic matrix of the silty and sandy claystones.

2. Rarely as brown to golden botryoidal masses, up to 0.3 mm in diameter, scattered in kaolinitic matrix.

3. As spherulites, 0.2 to 0.4 mm in diameter, with fibro-radial structure and sometimes a nucleus made up of a microgranular aggregate of siderite and clay particles (Pl. XXI B, C, and D). In some of the spherulites the fibro-radial structure is only faintly visible, or completely obliterated, probably because of recrystallization. In one sample, H20, the spherulites have a thick oxidation rim around them, and some are completely oxidized. The spherulites are generally found scattered in the kaolinitic groundmass of the finer-grained claystones containing just a little silt and very little or no sand grains.

4. As a concentration of spherulites, few of which show any fibro-radial structure, and prismatic crystals with very little interstitial silty-clay matrix between the sideritic elements (Pl. XXI A). The spherulites have, on the average, smaller size than the crystals, both keeping within the ranges given above.

Siderite spherulites of the same type as the ones in the Whitemud have been described from the fresh-water coaly deposits of the Carboni-

ferous of Belgium where they occur either scattered in kaolinite matrix or concentrated as thin beds and lenses of spherosiderite in the clayey intercalations of the coal seams. Kaisin (1943) and Scheere (1955), who studied these occurrences in detail, agreed on a primary origin for the siderite which would have been chemically precipitated at the bottom of the _lagune houllière_ at the same time as the detrital sedimentation of the clay. The precipitation of siderite requires a high Fe^{++}/Fe^{+++} ratio, alkaline pH, and a low Eh of the environment (Krumbein and Garrels, 1952). The main obstacle to a synsedimentary precipitation of siderite in the Carboniferous lagoons is undoubtedly the low pH that one must assume for these waters which are rich in CO_2 produced by the fermentation of organic matter. Scheere (_op. cit._) explains that a high pH can be produced as a result of the assimilation of CO_2 by the aquatic plants living in the lagoon. Oscillations in the pH of lacustrine waters due to living plants have in fact been recorded by Van Meel (1953) in Lake Upemba, Congo. The primary siderite deposited in crystalline form would then, during diagenesis, and after the formation of the underlying coal bed, be reorganized as spherulites. The diagenetic processes could therefore, according to Scheere, produce isolated spherulites of the type shown in Plate XXI B, C, and D, or they could bring about concentrations of the type of Plate XXI A where the closely packed particles show mutual interference.

An early diagenetic origin for the siderite spherulites of the Whitemud Formation is more likely, however, in the light of recent research. Hodgson (1968), in a study of calcite and rhodocrosite spherulites of Cretaceous-Tertiary age in New Zealand, concluded that carbonate

spherulites are produced during early diagenesis in a closed system under the influence of decomposition of organic matter, in the freshly buried sediments. Hodgson's conclusions were reached from the petrographic and isotopic study of ancient spherulites and of spherulites artificially precipitated in the laboratory.

As an alternative hypothesis for the concentration of siderite spherulites and crystals in the spherosiderite of Plate XXI A, one could possibly postulate a local reworking of the claystone beds and mechanical concentration of the spherulites and crystals that were scattered throughout the claystones. The well-rounded outline of the crystals, the dark oxidation rims around the grains, and especially the lack of clearly euhedral crystals or of a crystalline mosaic, could be interpreted as evidence of a detrital origin.

Edmonton Formation

In the Edmonton Formation, siderite is generally present in the ironstones that are particularly abundant well below the zone examined in this study. In the Battle Member no siderite was noticed. In the sediments underlying the Battle, authigenic nodules of siderite intergrown with biotite have been found in some sandstones (Pl. XXI E), and finely disseminated authigenic siderite crystals have been found in a silty shale approximately 6 meters below the base of the Battle.

In the rest of the Edmonton Formation, siderite is generally found associated with the ironstones that occur throughout the unit and whose origin is explained, by Allan and Sanderson (1945), by a process called "pool induration". Evaporation in shallow pools would have

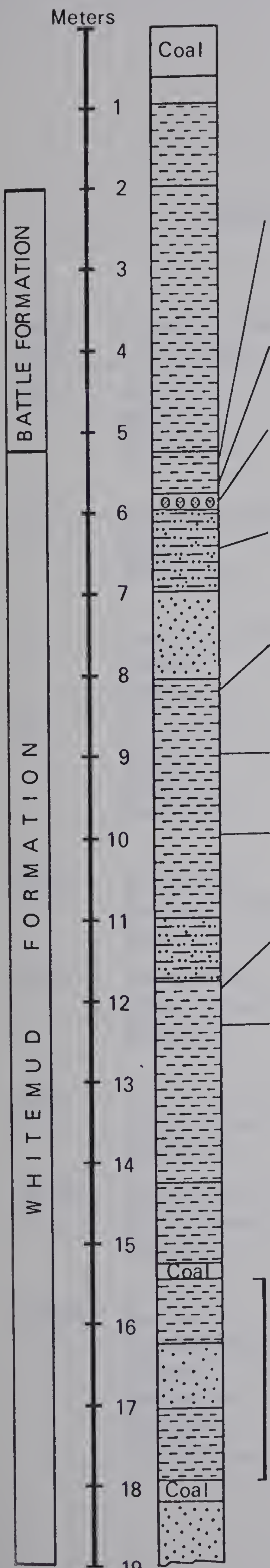
precipitated salts to cement the sand grains carried into the pools by rivers. Although the study of the ironstones was not a part of this thesis, it is perhaps appropriate to refer to Millot (1964, p. 183) who concluded that the siderolithic facies of the geologic column, among which the ironstones of the Edmonton Formation can be classified, represent the "... reliquat, remanié ou non, de grandes alterations de type intertropical humide ou lateritique au sense large." It is also significant that the pollen assemblage of the Lower Edmonton, where the ironstones are more conspicuous, indicates tropical to subtropical, humid, climatic conditions (Srivastava, 1968a).

ISOTOPIC ANALYSIS

Siderite concretions and spherulites were mechanically isolated from the clay matrix, ground to a fine powder, and checked by X-ray diffraction. The ground powder was then reacted under vacuum with 100 percent phosphoric acid (McCrea, 1950). The carbon dioxide thus obtained was then analyzed in a mass spectrometer equipped with a double collecting system. The results shown in Figure 17 and Table IX are expressed in conventional δ values indicating the difference between the ratio of the isotopes C^{13} and C^{12} (or O^{18} and O^{16}) in the sample to that of a chosen standard according to the formula:

$$\delta C^{13}\ \text{‰ (per mil)} = \frac{C^{13}/C^{12}\ \text{sample} - C^{13}/C^{12}\ \text{standard}}{C^{13}/C^{12}\ \text{standard}}$$

All values were corrected to the Chicago PDB standard, and an acid correction factor of αsiderite = 1.01169 was applied (Clayton, pers. comm.).



Sample No.	Description of material	Isotopic composition $\delta O^{18}PDB$	$\delta C^{13}PDB$
H 2	Siderite spherulites up to 0.2 mm diameter in clay matrix	−7.2	+3.6
H 1	Prismatic siderite crystals, 0.7 mm long, 0.2 mm diameter, in clay matrix	−7.8	−1.1
H 11	Siderite spherulites, up to 0.4 mm diameter, in a sphaerosiderose bed	−7.2	+7.7
H 12	Prismatic siderite crystals, twinning, 0.7 mm long, 0.2 mm diameter in clay matrix	−7.2	+2.6
H 14	Siderite spherulites up to 0.3 mm diameter, in clay matrix	−7.0	+2.5
H 15	As above	−7.2	+7.3
H 16	Siderite spherulites up to 0.4 mm diameter in clay matrix	−7.3	+6.7
H 19	As above	−9.4	−0.7
H 20	Siderite spherulites up to 0.4 mm diameter almost completely oxidized, in clay matrix	−12.2	+2.5

Abundant vegetal microfossils and fossil leaves (fresh-water)

FIGURE 17

Stratigraphic section near Eastend, Cypress Hills, and isotopic composition of the siderites

TABLE IX

Isotopic Composition of Siderites of the Edmonton Formation

Sample No.	Locality and Horizon	Description	Isotopic Composition δO^{18}PDB	δC^{13}PDB
E18	Scollard, Upper Edmonton	Sideritic concretionary band 15 cm thick in sandstone; 13 m above coal seam	-14.9	-2.7
WL15	Wizard Lake, Middle Edmonton	Authigenic siderite in bentonitic sandstone; 6 m above coal seam (drill-core sample)	-11.3	+5.8
α18	Red Deer River, Middle Edmonton	Authigenic siderite in bentonitic sandstone; 4 m above coal seam	-13.4	+3.0
A9	Horseshoe Canyon, Middle Edmonton	Oxidized fine diagenetic siderite in silty shale with carbonaceous vegetal remains and megaspores of Azolla sp.	-7.8	+11.8
HC8A	Horseshoe Canyon, Middle Edmonton	Clay ironstone concretions, 10 cm in diameter	-7.8	+8.5
HC13	Drumheller area, Lower Edmonton	Clay ironstone band underlying 20 cm of coal; 11 m above Drumheller Coal Seam	-7.8	+12.8
HC12	Drumheller area, Lower Edmonton	Clay ironstone band, 9 m above Drumheller Coal Seam	-9.7	+10.1
HC10B	Drumheller area, Lower Edmonton	Early diagenetic siderite concretions, 2-3 cm diameter; 2 m above Drumheller Coal Seam	-7.6	+12.7
HC15B	Hoodoos, Drumheller; contact Edmonton-Bearpaw Formations	Flat siderite concretions 5 cm diameter	-7.7	+8.4

The δC^{13} and δO^{18} values of the samples are given in Figure 17 and Table IX. It can be noticed immediately that, with the exception of one sample from the Upper Edmonton, and two from the Whitemud, the large majority of the samples have positive δC^{13} values. Such δC^{13} values would indicate, according to Weber *et al.* (1964) a marine depositional environment.

When the first four samples from the Whitemud and two from the Middle Edmonton yielded their astonishingly marine δC^{13} values, more samples from undoubtedly continental portions of the Edmonton Formation were collected and analyzed. Thus sample A9 was selected because it contains megaspores of the fresh-water fern *Azolla*, and samples from the Lower Edmonton because of the undoubted continental character of its vertebrate fauna and angiosperm microflora (Srivastava, 1968a). The siderite-bearing samples of the Whitemud do not contain any fossil remains, but only three meters (10 feet) below H20 there is an abundant fresh-water fossil assemblage. Since there is no indication that a drastic change of environment took place in the lapse of time represented by the intervening sediments, it can be assumed that the depositional environment of the siderite-bearing beds was more or less the same as the one indicated by the fossil assemblage that includes the water-lily leaves of Plate XXI F and the fragments of cat-tail of Plate XXI G.

When the new samples also yielded "marine" δC^{13} values, the validity of the criterion proposed by Weber *et al.* (1964) was questioned, and alternative explanations were sought.

The enrichment in C^{13} with respect to C^{12} in the diagenetic environment in which the spherulites were formed can be explained in several ways.

If fragments of marine carbonates were present in the detrital fraction, their dissolution would supply "heavy" carbon dioxide to the environment. Although this possibility cannot be substantiated by petrographic evidence, it cannot be completely discarded. The influence of dissolved "marine" carbon would, however, be slight in the environment.

A more likely mechanism of enrichment in C^{13} is of a biochemical nature. Experiments by Rosenfeld and Silverman (1959) showed that the gases produced in the decomposition of organic substances by bacteria become progressively richer in C^{13} toward the end of the reaction. If we now assume that the decomposition of the vegetal matter of the coal seams that are abundant in the section started early in the history of the deposit, we can envisage that the C^{12}-rich carbon dioxide escaped rather easily from the sediments, bubbling through the water of the lake. The bubbling of surface waters of swamps and ponds by decomposition of organic matter is an observable fact. If only the carbon dioxide produced near the end of the reaction, the one enriched in C^{13}, was trapped by the sediments, and combined with Fe to give the siderite spherulites of the Eastend section, the "anomalous" δC^{13} of the latter could be explained.

Another organic mechanism of enrichment in C^{13} can be supported by the research of Rosenfeld and Silverman (1959). At any stage of the decomposition of organic matter, the formation of C^{12}-rich methane produces, not only an enrichment in C^{13} of the source, but also, simul-

taneously, carbon dioxide enriched in C^{13}, owing to the very large fractionation factor between CO_2 and methane (Craig, 1953). This mechanism would not require the escape of "light" carbon dioxide from the system.

Mechanisms very similar to the two expressed above have been invoked by Murata et al. (1967) to explain anomalously heavy carbonates in Miocene rocks of California.

If the C^{13}/C^{12} isotopic ratios of the Edmonton and Whitemud are in apparent disagreement with a fresh-water origin, the O^{18}/O^{16} ratios fit published data on fresh-water carbonates. All the δO^{18} values are in fact well below the -2‰ lower limit that is characteristic of marine carbonates of present-day oceans. The study of Cretaceous marine carbonates indicates a slight shift toward more negative values, and a lower limit of -5‰ is generally accepted (Keith and Weber, 1964). All the δO^{18} values of Figure 16 and Table IX are, however, well below -5‰, thus indicating a fresh-water environment depleted in O^{18}.

REMARKS ON THE DEPOSITIONAL ENVIRONMENT

The O^{18}/O^{16} isotopic ratios of the siderites of the upper member of the Whitemud Formation of Saskatchewan and of the sediments underlying the Battle Member in the Alberta Plains indicate fresh-water depositional environment, thus being in perfect agreement with micropaleontologic and sedimentologic data.

The C^{13}/C^{12} ratios of the same siderites, however, are in disagreement with what Weber et al. (1964) consider to be indicative of

fresh-water conditions. Since siderites of undoubtedly fresh-water sediments in the Middle and Lower Edmonton also yield anomalously "marine" δC^{13} values, the environmental criterion proposed by Weber et al. is considered not applicable to diagenetic siderites.

The environmental indications obtained from the isotopic composition of the siderites can be considered in agreement with the micropaleontologic and sedimentologic data, if the anomalous δC^{13} values are explained in terms of an enrichment in C^{13} of the carbon dioxide during diagenesis.

CHAPTER SEVEN - MICROFOSSIL ASSEMBLAGES

GENERAL RESULTS OF THE MICROPALEONTOLOGICAL INVESTIGATION

As already stated (p. 8), a detailed micropaleontological investigation of the Battle Member of the Edmonton Formation and subjacent beds, and of their equivalents in the Cypress Hills, was deemed to be of primary importance. It was necessary to investigate the frequent "rumours" of foraminiferal findings in these strata such as the one recorded in Campbell (1962).

One hundred and thirty-five samples of claystones from the Battle Member of the Edmonton Formation and the Battle Formation were examined for microfossils. They were collected from 21 different outcrops (17 in the Alberta Plains, Wintering Hills and Hand Hills; 4 in the Cypress Hills) and from one well core (Wizard Lake). The microfossil yield was indeed very poor: only 34 samples (about 25%) yielded fossil remains, with an average of 6 to 8 specimens per 100 grams of sediment. Samples with 20 to 30 specimens were extremely rare and only one yielded more than 100 microfossils.

More than 70 samples from the sandstones, siltstones, claystones and coal beds underlying the Battle Member and the Battle Formation were analyzed. The name "White Sandstone", as it is used here, is not restricted to such a lithological type. It refers instead to the beds underlying the dark shale and it is not used *sensu* Sanderson (in Allan and Sanderson, 1945), but includes sedimentary beds of the upper part of the Middle Edmonton Formation for up to six or seven

meters below the lower contact of the Battle Member, because any break or discontinuity in the fossil record at this particular level is usually due to lithology and preservation. Light brown claystones in proximity to coaly beds gave the most abundant assemblages, whereas light colored siltstones and claystones yielded very little and often nothing at all, and sandstones were mostly negative.

Not a single microfossil that could possibly be identified as a foraminifer, or part of one, was found in any of the more than 200 residues examined. Two distinct types of vegetal microfossil assemblages were found in the stratigraphic units under study. The sediments of the upper part of the Whitemud Formation and the sediments of the "White Sandstone" are in fact characterized by an assemblage consisting of megaspores and cuticles attributable to fossil seeds. The claystones of the Battle Formation and of the Battle Member yielded a very typical microflora consisting of a few species of megaspores mineralized in opaline silica, an unusual form of preservation indeed, although not totally new in the palynological literature.

PREVIOUS PALEOBOTANICAL AND PALYNOLOGICAL WORK

Bell (1949) described 24 species of plant remains from the Edmonton Formation. These species are distributed among 14 families as follows: Equisitae 1, ferns 1, cycadophytes 3, ginkophytes 3, conifers 6, dicotyledons 10.

The total assemblage was divided into two subfloras that characterize an Upper and a Lower Edmonton with the Kneehills Tuff bed marking the boundary between the two.

Subflora of the Upper Edmonton:

Filicites knowltoni Dorf
Carpolithus (_Cycadinocarpus?_) _ceratops_ (Knowlton)
Sequoiites dakotensis Brown
Platanus raynoldsii integrifolia Lesquereux
Platanophyllum sp.
Anona robusta Lesquereux
Nymphaeites angulatus (Newberry) Bell
Vitis stantoni (Knowlton) Brown
Fraxinus leii Berry

Subflora of the Lower Edmonton:

Equisetum perlaevigatum Cockerell
Nilssonia sp.
N. serotina Heer
Ginkgoites sp.
Carpolithus (_Ginkgoites?_) _fultoni_ Bell
_C._ (_Ginkgoites?_) _kneehillensis_ Bell
Torreyites tyrrellii (Dawson) Bell
Cunninghamiostrobus ? sp.
Sequoiites artus Bell
S. dakotensis Brown
Elatocladus intermedius (Hollick)
Thuiites interruptus (Newberry)
Juniperites gracilis (Heer) Seward and Conway
Trochodendroides arctica (Heer)
Jenkinsella arctica (Heer) Bell
Dombeyopsis nebrascensis (Newberry) Bell
Nymphaeites angulatus (Newberry) Bell
Vitis stantoni (Knowlton) Brown

The presence of four diagnostic species, namely _Filicites knowltoni_, _Carpolithus ceratops_, _Anona robusta_ and _Fraxinus leii_ made Bell (_ibid._) conclude Upper Edmonton to be of Lance age. A correlation with the Frenchman Formation is also suggested by the occurrence of _C. ceratops_ and _F. leii_.

Srivastava (1965, 1966, 1967) studied the microflora of part of the Edmonton Formation from about 70 feet below to 150 above the Kneehills Tuff bed at Scollard. One hundred species of pollen and spores were described. The presence of the following modern families or higher taxa was indicated: Sphagnaceae, Lycopodiaceae, Selaginellaceae,

Marattiaceae, Osmundaceae, Polypodiaceae, Schizaeaceae, Gleicheniaceae, Cyatheaceae, Salviniaceae, Cycadales or Bennettitales, Taxodiaceae, Cupressaceae, Araucariaceae, Podocarpaceae, Pinaceae, Liliaceae, Myricaceae, Fagaceae, Salicaceae, Betulaceae, Ulmaceae, Aquifoliaceae, Oleaceae, Symplocaceae, Proteaceae, Loranthaceae.

The Scollard section was divided by Srivastava (1965 and 1967) into five Microfloral Assemblages, of which I, II, and III characterize the sediments below the Kneehills Tuff bed, whereas IV and V are typical of the section above the tuff. Study of these assemblages seems to indicate environmental conditions starting with a "rich swamp forest" growing in warm, humid, tropical climate, bordered by a "podocarpaceous and cupressaceous vegetation" with possible coniferous vegetation at a greater distance. Srivastava (ibid.) envisages a change to hydrosere stages and then to swampy sere in Microfloral Assemblage II (48 to 50 feet below K.T.). The establishment of a sere of cooler climate is suggested by Microfloral Assemblage IV, but throughout the sequence of Microfloral Assemblage V (90 to 150 feet above K.T.) a rich vegetation was restored with indications of "...subtropical climate with the vestiges of tropical elements and the introduction of dicotyledonous flora with more of a subtropical to warm temperate aspect." Unfortunately, Microfloral Assemblage III, covering most of the depositional interval that is the object of the present study, is composed only of unidentified "comminuted fragments" in section 1 of the Scollard locality.

Srivastava (1968a) recognizes eight pollen zones and one spore zone in the Edmonton Formation of the Red Deer River Valley between

Scollard and Drumheller. Srivastava's biostratigraphic subdivision includes from top to bottom:

IX	Wodehousea fimbriata Zone
VIII	Wodehousea spinata Zone
VII	Azolla and Balmeisporites-bearing Interval
VI	Scollardia trapaformis Zone
V	Mancicorpus vancampoi Zone
IV	Pulcherripollenites krempii Zone
III	Wodehousea jacutense and W. gracile Zone
II	Aquilapollenites leucocephalus Zone
I	Transitional Zone

The biostratigraphic units that cover the lithologic intervals studied in the present work are the Wodehousea spinata Zone (VIII), extending from the base of the Battle Member (Blackmud M.) to the top of the Nevis coal seam, and the Azolla and Balmeisporites-bearing Interval (VII) extending from the top of the coal seam 34 feet below the Kneehills Tuff to about 14 feet below the Kneehills Tuff. It is significant perhaps that these intervals have also yielded microfloral assemblages that can be considered depauperate in comparison with the rest of the Edmonton Formation.

Other palynological papers on the Edmonton Formation include work by Hills and Weiner (1965) relating to the occurrence of a new species of Azolla in the Upper Edmonton and by Snead (1969) on the Cretaceous-Tertiary boundary in Southern Alberta. Several papers by Srivastava on the Edmonton Formation have recently appeared in the literature. Among these one deals with fungal microfossils (Srivastava, 1968b), two deal with the taxonomy of Mancicorpus and of Aquilapollenites (Srivastava, 1968c and 1969), and one relates to some species of Azolla (Srivastava, 1968d).

Certain material discussed in this thesis has already been published in the following three articles: Binda and Srivastava (1968)

on the silicified megaspores of the Battle; Binda (1968) on some Spermatites of the Edmonton; Srivastava and Binda (1969) on Balmeisporites of the Edmonton and Whitemud Formations.

The following 26 vegetal species were described by Berry (1935) from the Whitemud Formation of southern Saskatchewan:

* Ampelopsis montanensis Cockerell (?)
* Equisetum sp.
Euonymus xantholithensis Ward (?)
* Ficus martini Knowlton (?)
* Ficus speciossima canadensis Berry
* Fucus lignitum Lesquereux
Ginkgo adiantoides (Unger) Heer
Grewia(?) sp. cf. G. crenata (Unger)
Hickoria antiquorum (Newberry) Knowlton (?)
Leguminosites arachioides minor Berry
* Menispermites belli Berry
* Nelumbo dawsoni Hollick
* Nelumbo tenuifolia (Lesquereux) Knowlton
* Nelumbites striata Berry
* Palmocarpon sp.
* Pistia corrugata Lesquereux
Platanus guillelmae heerii Knowlton
Sequoia nordenskioldii Heer
* Smilax(?) inquirenda Knowlton
Thuja interrupta Newberry
Trapa(?) cf. T. microphylla Lesquereux
Viburnum antiquum (Newberry) Hollick
* Viburnum marginatum Lesquereux
Viburnum sp.
* Vitis dakotana Berry
Zizyhus coloradensis Knowlton

The forms marked by the asterisk have not been found in the overlying Ravenscrag Formation. It is to be borne in mind that what Berry called Ravenscrag includes also the Frenchman Formation which was designated much later by Furnival (1946). On the basis of the floral remains listed above, Berry (op. cit.) suggested a late Late Cretaceous age for the Whitemud Formation "... in a general way to be correlated with the Laramie, in the restricted modern sense of that term".

SAMPLE PREPARATION

Since the aim of this investigation was the detection of whatever fossil remains were present in the rocks under study, and since foraminifera had been reported or "rumored" to occur in them, it was decided to adopt standard micropaleontological techniques without the use of acids. This procedure proved most rewarding as it led to the discovery of the unique silicified megaspores of the Battle.

Two different sets of techniques were necessary for the preparation of the silicified microfossils from the Battle, and for the preparation of the non-petrified megaspores and cuticles from the underlying sediments.

Megaspores and Seed Cuticles from the Whitemud Formation and the "White Sandstone"

The claystones and siltstones were disaggregated in water and common detergent, shaken in a rotary blender and then wet-sieved through a 149 microns sieve. The microfossils were then picked under a stereoscopic microscope. A few specimens had to be treated with hydrofluoric acid in order to eliminate clay encrustations. The microfossils were then divided into three groups according to the different amounts of oxidation required.

A first group, composed mostly of *Spermatites* and other thin seed cuticles, required no oxidation at all or up to 2 minutes in nitric acid. A second group with *Balmeisporites*, *Costatheca*, and some thin-walled megaspores, required from 2 to 10 minutes in HNO_3 and K_2CO_3. Finally, a third group including *Azolla* and *Erlansonisporites*

had to be left for up to 2 hours in the oxidizing solution. The progress of the oxidation was constantly checked under the microscope.

After oxidation, the fossils were washed in water, treated for 10 minutes with 98 percent ethyl alcohol, then put in xylene for 5 to 10 minutes and finally permanently mounted in Canada balsam.

A number of modern seeds were also treated and artificially "fossilized" for comparison purposes. In order to remove the protoplasmatic content the following techniques were employed:

(a) Erdtman's acetolysis process as described by Brown (1960, p. 8-12). This method did not prove very successful.

(b) The specimens were boiled for 10 to 20 minutes in a 10 percent solution of KOH after having small holes pierced through the cuticles. Although this method presented some difficulties and 90 percent of the seeds were lost through breakage, leaving only 10 percent usable, it still gave better results than the acetolysis.

Silicified Microfossils from the Battle Member and the Battle Formation

The claystones were soaked in water and detergent, shaken in a rotary blender and sieved through a set of sieves with openings of respectively, 250, 149 and 74 microns. The residues thus obtained were separately dried in an oven and the megaspores were picked under a binocular microscope.

Thin sections were made applying standard techniques used for foraminifera.

A few residues from the fraction collected on the 74 microns sieve were passed through a Frantz Isodynamic Separator at 1.5 Amperes and 5° tilt. The non-magnetic fraction was run three times in order to clean it from the residual clay lumps and magnetic minerals, then mounted with Arochlor and examined for finer siliceous fragments. Some samples of finer grained material passing through the 75 microns sieve was cleaned by decanting off the minus 5 microns fraction and then divided into two fractions, one finer and one coarser than 30 microns. The separation of the minus 30 microns fraction was obtained by pipetting from a depth of 10 cm from a beaker, 1 minute and 56 seconds after stirring the suspension (Folk, 1961, p. 39). Grain mounts of the two fractions were then analyzed under the microscope.

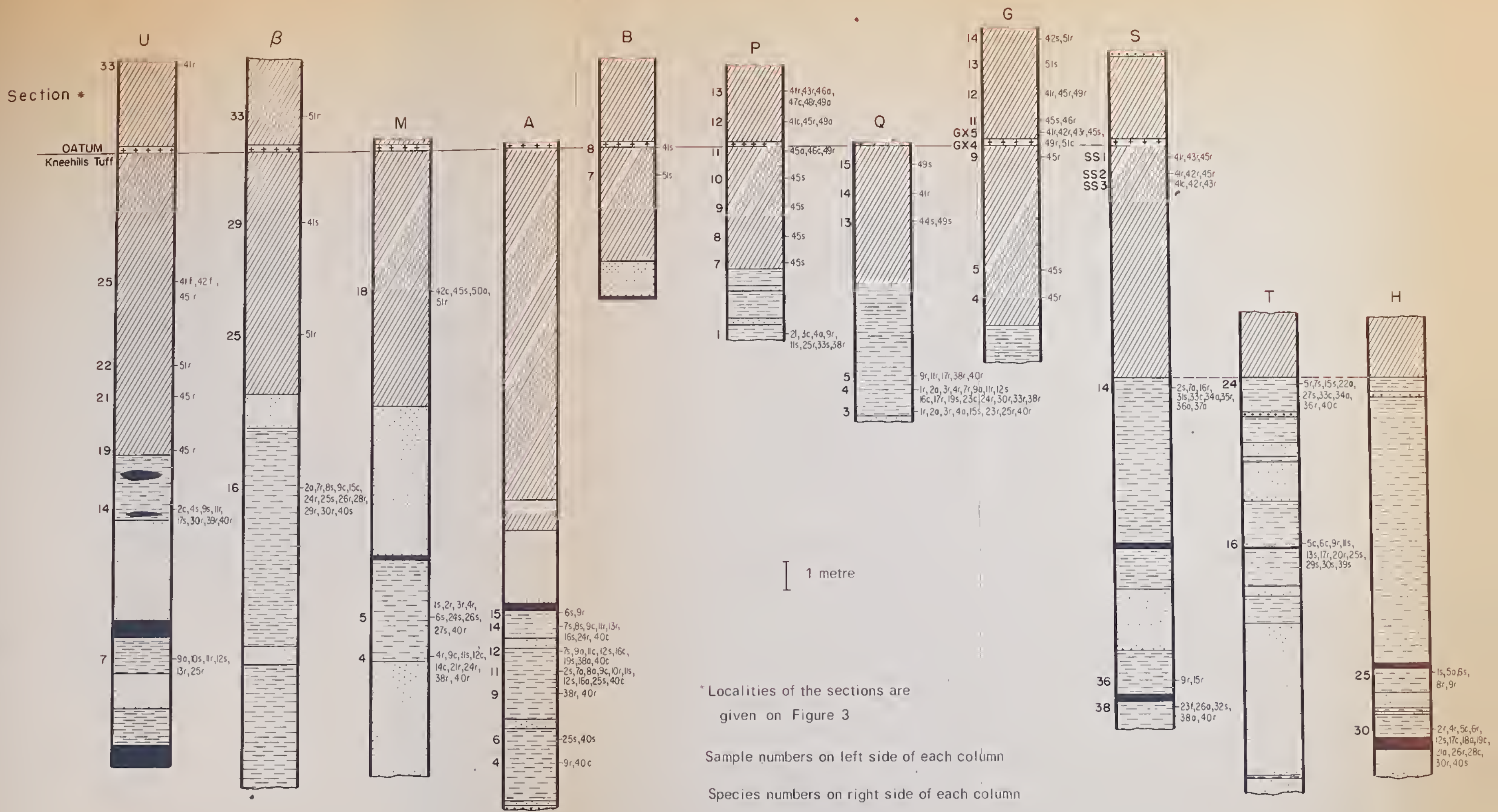
MICROFOSSIL ASSEMBLAGES

Microfossils of the "White Sandstone" and Whitemud Formation

"White Sandstone"

The sediments underlying the Battle Member in the Alberta Plains contain abundant microscopic vegetal remains in their shaly and silty parts (U14, P1, Q3-5 of Fig. 18), whereas they are generally barren in their more sandy facies.

FIGURE 18 Stratigraphic Distribution Of Vegetal Microfossils



* Localities of the sections are given on Figure 3

Sample numbers on left side of each column

Species numbers on right side of each column

KNEEHILLS TUFF

BATTLE FM and BATTLE MEMBER OF THE EDMONTON FM

Sandstone

Claystones and Siltstones } WHITEMUD FM and EDMONTON FM (Middle Member)

Coal and highly Carbonaceous shales

Iron concretions

VEGETAL MICROFOSSILS

1 *Spermatites nanus*
2 *S. ellipticus minor*
3 *S. minimus*
4 *S. piperiformis*
5 *S. saskatchewanicus*
6 *S. pinguis*
7 *S. robustus*
8 *S. sp.*
9 *Costatheca striata*
10 *C. inflata*
11 *C. minerii*
12 *C. exilis*
13 *C. lata*
14 *C. pusilla*
15 *C. sp.*
16 *Carpotheca elegans*
17 *C. coronata*
18 *C. parva*
19 *C. falcata*
20 *Triletes srivastavae*
21 *Minerisporites mirabilis*
22 *Warrenisporites spinosus*
23 *Erlansonisporites singhii*
24 *E. augustus*
25 *E. sp.*
26 *Balmeisporites bellus*
27 *B. canadensis*
28 *B. kondinskayae*
29 *B. densireticulatus*
30 *B. sp.*
31 *Megaspore type A*
32 *Megaspore type B*
33 *Azolla sp. A*
34 *A. sp. B*
35 *A. sp. C*
36 *A. sp. D*
37 *A. sp. E*
38 *A. sp. F*
39 *A. sp.*
40 *A. sp.*
41 *Henrisporites granulatus*
42 *H. elkwaterensis*
43 *H. sheilae*
44 *Verrutriletes albertensis*
45 *Horstisporites canadensis*
46 *Stelkisporites standardensis*
47 *S. tenuistriatus*
48 *S. verrucosus*
49 *S. sp.*
50 *Selenasporites reticulatus*
51 *Unidentified silicified megaspores*

FREQUENCE IN 100 g OF SEDIMENT:

s = single = l
r = rare = 2-4
c = common = 5-9
a = abundant = 10-49
f = flood => 50

The following twenty-nine species of vegetal microfossils were found in these sediments:

Costatheca striata (Dijkstra) Hall
C. inflata sp. nov.
C. minerii sp. nov.
C. exilis (Vangerow) Hall
C. lata (Vangerow) Hall
C. pusilla sp. nov.
Spermatites nanus Miner
S. ellipticus minor Binda
S. minimus Binda
S. piperiformis Binda
S. pinguis sp. nov.
S. robustus sp. nov.
Carpotheca elegans sp. nov.
C. coronata sp. nov.
C. falcata sp. nov.
Minerisporites mirabilis (Miner) Potonie
Erlansonisporites singhii sp. nov.
E. augustus sp. nov.
Balmeisporites bellus Kondinskaya
B. canadensis Srivastava and Binda
B. kondinskayae Srivastava and Binda
B. densireticulatus sp. nov.
B. sp.
Azolla sp. A, cf. *A. filosa* Snead
A. sp. B
A. sp. D
A. sp. E
A. sp. F
A. sp. G

Whitemud Formation

Twenty-nine species of vegetal microfossils and two unidentifiable types have been recovered from sediments of the Whitemud Formation of the Cypress Hills (sections S, T, and H of Fig. 18).

Costatheca striata (Dijkstra) Hall
C. minerii sp. nov.
C. exilis (Vangerow) Hall
C. lata (Vangerow) Hall
Spermatites nanus Miner
S. ellipticus minor Binda
S. piperiformis Binda
S. saskatchewanicus sp. nov.
S. pinguis sp. nov.
S. robustus sp. nov.
Carpotheca elegans sp. nov.
C. coronata sp. nov.
C. parva sp. nov.
C. falcata sp. nov.
Triletes srivastavae sp. nov.
Minerisporites mirabilis (Miner) Potonie
Warrenisporites spinosus sp. nov.
Erlansonisporites singhii sp. nov.
Balmeisporites bellus Kondinskaya
B. kondinskayae Srivastava and Binda
B. canadensis Srivastava and Binda
B. densireticulatus sp. nov.
Megaspore type A
Megaspore type B
Azolla sp. A, cf. *A. filosa* Snead
A. sp. B
A. sp. C
A. sp. D
A. sp. E
A. sp. F
A. sp. G

Relative Abundance and Distribution

The stratigraphic distribution and frequency of the microfloral elements is given in detail in Figure 18. The chart, however, illustrates only eleven typical sections, whereas vegetal microfossils were

recovered from seven more localities of which six are in the Alberta Plains and one in the Cypress Hills.

Table X has been compiled on the basis of the total recovery. The semi-quantitative designations such as Very Rare, Rare and Common, illustrate the overall distribution, that is the frequency of the taxa in the individual samples and the occurrence in different sections. Thus, taxa that may be locally very abundant may be designated as Rare in the list if their occurrence is limited to a small number of localities.

From Table X have been excluded three fossils for which only one specimen of each was found and no specific designation was given.

The comparison of the fossil recovery from the two areas shows without any doubt that the assemblages are basically the same. Only eight species were not found in both areas, and of these, six are rare in the area where they are present, one is very rare and only one is common. Of the seed cuticles, the genus *Costatheca* and the subspecies *Spermatites ellipticus minor* seem to be more abundant in the Alberta Plains, whereas *Carpotheca*, especially the curved type, *C. falcata*, is better represented in the Cypress Hills, together with *Spermatites saskatchewanicus*. Among the megaspores only a few species are peculiar to the Cypress Hills area, with the overall assemblage being very much the same.

No vertical variation of the microfossil assemblage was noticed in this small interval. The same type of assemblage is present, both in the Alberta Plains and in the Cypress Hills, from

TABLE X

Relative Abundance and Distribution of Microfossils in the "White Sandstone" and Whitemud Formation

Microfossil	"White Sandstone" (Alberta Plains)	Whitemud Formation (Cypress Hills)
SEED CUTICLES		
Costatheca striata	Common	Rare
C. inflata	Very Rare	Not Found
C. minerii	Rare	Very Rare
C. exilis	Rare	Very Rare
C. lata	Rare	Very Rare
C. pusilla	Rare	Not Found
Spermatites nanus	Rare	Very Rare
S. ellipticus minor	Common	Rare
S. minimus	Rare	Not Found
S. piperiformis	Common	Rare
S. saskatchewanicus	Not Found	Common
S. pinguis	Very Rare	Common
S. robustus	Rare	Common
Carpotheca elegans	Common	Rare
C. coronata	Rare	Common
C. parva	Not Found	Rare
C. falcata	Very Rare	Common
MEGASPORES		
Triletes srivastavae	Not Found	Rare
Minerisporites mirabilis	Rare	Rare
Warrenisporites spinosus	Not Found	Rare
Erlansonisporites singhii	Common	Common
E. augustus	Rare	Rare
Balmeisporites bellus	Rare	Common
B. canadensis	Very Rare	Very Rare
B. kondinskayae	Rare	Common
B. densireticulatus	Rare	Very Rare
Azolla sp. A	Rare	Common
A. sp. B	Rare	Common
A. sp. C	Not Found	Rare
A. sp. D	Rare	Rare
A. sp. E	Rare	Common
A. sp. F	Common	Common
A. sp. G	Rare	Very Rare

the lower contact of the dark claystones downward for the 8 to 10 meters that have been examined. No microfossil boundary or break can be detected at lithological breaks: when the "White Sandstone" is a true sandy to silty horizon, it does not carry any microfossils, whereas light brown claystones are usually fossiliferous yielding the same general assemblage regardless of whether they occur right below the Battle or anywhere else in the studied interval.

Whether or not this assemblage represents a true zone, is, for the time being, impossible to tell. Not enough detailed stratigraphic work has been done on the megaspores and seed cuticles of the Upper Cretaceous to be able to use these microfossils with the confidence required for such a refined definition.

The correlation between the "White Sandstone" of the Edmonton Formation and the Whitemud Formation of the Cypress Hills will have therefore to be subordinated to the aforementioned consideration. It is felt, however, that on the basis of the vegetal microfossil assemblage, the portion of the Edmonton Formation to be correlated with the Whitemud Formation is not the White sandstone *sensu* Sanderson (in Allan and Sanderson, 1945), but an interval that includes a larger portion of the Middle Edmonton below the typical white beds.

Microfossils of the Battle

The Battle Member of the Edmonton Formation and the Battle Formation of the Cypress Hills yield the same types of microfossils. All the vegetal microfossils noticed in the two stratigraphic units

are preserved as opaline silica rather than as organic matter, as is the case for similar remains throughout the Edmonton Formation and its equivalents from the Cypress Hills.

The silicified microfossil assemblage is composed of megaspores, microspores, pollen grains, fungal elements, and tracheids. Of the assemblage, the only microfossils that have been identified at a specific level are the megaspores.

The microspores and pollen grains have been observed both in thin sections and in grain mounts. Their identification presents some technical problems, since the details of the ornamentation cannot be satisfactorily seen with transmitted light and their size is too small for a study under a stereoscopic microscope. It is felt here that a study of these microfossils by scanning electron microscope could be rewarding.

A large number of "rod-shaped" silicified vegetal fragments ranging in length from 50 to 200 microns, and a few microns to a few tens of microns in diameter are also present in the Battle. They are silicified fragments of tracheary elements of the xylem of vascular plants (Esau, 1965). They are mostly of the annular and helical type (Pl. VI, figs. 9, 10, 11) but a few reticulate and pitted fragments have also been noticed.

A few silicified fragments that resemble fungal sporangia and other fungal elements, have also been noticed.

Battle Member

The following nine species of megaspores preserved as opaline fossils were identified:

Henrisporites granulatus Binda and Srivastava
H. elkwaterensis Binda and Srivastava
H. sheilae Binda and Srivastava
Verrutriletes albertensis Binda and Srivastava
Horstisporites canadensis Binda and Srivastava
Stelckisporites standardensis Binda and Srivastava
S. tenuistriatus Binda and Srivastava
S. verrucosus Binda and Srivastava
Selenasporites reticulatus Binda and Srivastava

Battle Formation

Only samples from Quarry 45 (section S of Fig. 18) yielded identifiable microfossils. The following four species of silicified megaspores were recognized:

Henrisporites granulatus Binda and Srivastava
H. elkwaterensis Binda and Srivastava
H. sheilae Binda and Srivastava
Horstisporites canadensis Binda and Srivastava

Relative Abundance and Distribution

The comparison of the relative abundance of the single elements within the assemblage given in Table XI has to take into account the fact that only samples from one of the sections in the Cypress Hills yielded any microfossils (see Fig. 18). This may explain why fewer species have been found in the Battle Formation than in the Battle Member.

TABLE XI

Relative Abundance and Distribution of Microfossils in the Battle Member and Battle Formation

MEGASPORES	Battle Member (Alberta Plains)	Battle Formation (Cypress Hills)
Henrisporites granulatus	Common	Common
H. elkwaterensis	Rare	Rare
H. sheilae	Rare	Rare
Verrutriletes albertensis	Very Rare	Not Found
Horstisporites canadensis	Common	Rare
Stelckisporites standardensis	Rare	Not Found
S. tenuistriatus	Rare	Not Found
S. verrucosus	Rare	Not Found
Selenasporites reticulatus	Rare	Not Found

The microfloral elements present in the Battle Formation are all represented in the Alberta Plains counterpart. Thus, the two units overlie beds carrying the same microflora, and both units carry a microflora that: (1) is characterized by four species found in both, (2) is different from the underlying assemblage, and, (3) is unique for its type of preservation. The two units are therefore treated here as correlative not only on the basis of lithological characters but on the strength of paleontological evidence.

Previous Recognition of Silicified Megaspores

Records of silicified or calcified spores are rare in the literature. This is partly due to the scarcity of such types of remains, and partly due to the current palynological techniques. Hydrochloric and hydrofluoric acids are the main reagents used by

palynologists in order to break down the samples and get rid of carbonates and silica. Such treatment would obviously destroy any silicified or calcified remains. Sahni and Rao (1943) described silicified megaspores and microspores from the Deccan intertrappean cherts of Cretaceous-Tertiary age. Although the material seems to be beautifully preserved, the fossils could only be studied in thin section. Rao (1943) and Vishnu-Mittre (1954) described a silicified microflora from thin sections of Jurassic rocks of the Rajmahal Hills, Bihar, India. Silicified spores have also been recorded by Goldstein (1959) in thin sections of the Arkansas Novaculite. Very few silicified microfossils have been isolated from claystones and shales. Sitholey (1943) described siliceous casts of megaspores assigned to the genus _Triletes_ from the Triassic of the Salt Range, Punjab. Taugourdau-Lantz and Rosset (1966) described under the name _Calcicarpinum_ ? _fallax_ a calcified microfossil of uncertain affinity from Oligocene sediments of the Narbonne Basin, France. Although the authors seem to exclude the idea of it being a megaspore, the specimens bear a Y mark that resembles very much a laesura with raised lips.

The silicified material described in the present study is to the author's knowledge the first record of isolated silicified megaspores with well preserved wall structure.

It is felt here that silicified megaspores, or rather fragments of the same, might have been fairly often misidentified by other workers. In the early stages of this research in fact, when only broken fragments were recovered, they were often identified as "fragments of ostracodes or foraminifera". In Plate VI, figures 1 to 8, it

is clearly shown how easily such a mistake can be made. It was not until a complete and well preserved specimen showing a prominent tetrad mark was found, that the real nature of the fossils became apparent.

The transformation of the original organic material to opaline silica seems to have taken place as a metasomatic replacement in the silica-rich diagenetic environment of the bentonites. As can be seen from the thin sections illustrated in Plates III, IV and V, some of the very finest features of the spore wall have been perfectly preserved, and the spore wall shows a distinct layering. It is interesting to note that some of the fossils have a hard chalcedonic or opaline nucleus and others are filled with a fragile lump of clay that swells in water, often breaking the outer siliceous wall.

AGE OF THE MICROFLORAL ASSEMBLAGES

The age of the Battle-Whitemud sequence has been extensively discussed by several authors, especially in the context of Upper Cretaceous dinosaur faunas and the Fox Hills-Lance problem. An extensive list of publications on the pre-Cenozoic vertebrate paleontology of Alberta is given by Langston (1965). Russell (1964) and Clemens and Russell (1965) chose the Kneehills Tuff as a convenient horizon to separate the Lancian stage, characterized by a typical <u>Triceratops</u> fauna and by the occurrence of mammals, from the underlying Edmontonian stage characterized by a pre-Lance dinosaur fauna. The Whitemud-Battle complex of the Cypress Hills is treated by

Clemens and Russell (*ibid*.) as correlative with the Colgate Sandstone of Montana, which unit, according to Clemens (1960), marks the transition between the Fox Hills and the Lance of the type area. The *Triceratops* Zone (or Lancian of Russell, *op. cit*.) has been equated by Jeletzky (1960) with the upper Maestrichtian of Europe, by means of indirect correlation, since the European stage is defined by marine fossils. Srivastava (1965 and 1968a) indicated a Maestrichtian correlation of the microfloral assemblages described above and below the Battle-"White Sandstone" complex of the Red Deer River valley. Absolute age determinations on bentonites of the Battle given by Folinsbee *et al*. (1961) and Shafiqullah (1963) also indicate a Maestrichtian age (65 $\pm$ 3 m.y.).

The aforementioned correlations would thus suggest that the deposition of the units under study took place around the end of the early Maestrichtian or the beginning of late Maestrichtian time. The direct comparison of the microfloral assemblages with microfloras already described does not bring any refinement as to the age, since the stratigraphic distribution of Cretaceous megaspores and seed cuticles has never been systematically studied. A few considerations on the elements of the assemblages described here and their relations with other American, European and Asian records can, however, be made.

(1) *Spermatites* has been recorded from Upper Cretaceous beds from Greenland, Iowa and Oklahoma (see Chapter Nine), but it was thought to be restricted to the Cenomanian (Hall, 1963). Hall states: "*Spermatites* is a heterogeneous genus but forms similar to Miner's

(1935) type occur only in the Cenomanian". Since there is no doubt that the forms described in the present work are very closely related to Miner's fossils, the range of Spermatites has to be extended to include at least the Maestrichtian.

(2) Costatheca (ex Chrysotheca) is a fossil of wide geographical distribution. It has been described from the Aachenian (lower Senonian) of Holland and Germany, from the Upper Cretaceous of Greenland, the Dakota Formation (Cenomanian) of Iowa and is present in the Wanship Formation (Danian-upper Maestrichtian) of northeastern Utah and southwestern Wyoming (see Chapter Nine). Although Hall (op. cit.) states that it "occurs only as late as the Senonian", it probably extends into the Paleocene. Dijkstra (1961) mentions some specimens of Costatheca found in Paleocene rocks of Epinois, Belgium. A very detailed study of the stratigraphic distribution of the various species of Costatheca would be extremely desirable. Its geographical distribution and its occurrence in continental beds of Upper Cretaceous-Paleocene age could be very useful for the correlation of marine and continental deposits of the extremely controversial part of the geological column and throw some light on the Cretaceous-Tertiary boundary problem.

(3) Balmeisporites has, to the author's knowledge, been reported only from Cretaceous deposits (Lower Cretaceous-Senonian) of Australia, New Guinea, Siberia and North America (see Chapter Nine). The species described in the present study are very similar to the ones that occur in the Senonian of the West Siberian Lowland (Kondinskaya, 1966). It is

felt that two megaspore species described by Norton and Hall (1967) as Styx major and S. minor from the Hell Creek Formation of eastern Montana are in fact Balmeisporites bellus.

(4) A number of long-ranging megaspore genera such as Minerisporites, Erlansonisporites, Horstisporites, etc. are represented here with species distinct from the ones already described from lower stratigraphic horizons.

DEPOSITIONAL ENVIRONMENT AS INDICATED BY VEGETAL MICROFOSSILS

Pollen and microspores should not be considered the best possible indicators of the environment of deposition of the rocks in which they are found. Most of these palynomorphs are shed by plants living in continental environments; however their easy transportability by wind and streams, leads them to be found in marine realms. On the other hand, megaspores and large vegetal microfossils such as Costatheca and other cuticles form a somewhat different category and they can be useful for the detection of paleoenvironmental conditions. Their larger size makes transport by wind relatively difficult. They float very well and can be transported by rivers and streams. A few specimens of Costatheca, associated with a scarce foraminiferal fauna, have been observed by the author in brackish-to-marine shales of the Bearpaw Formation of southwestern Saskatchewan. However, abundant and well-preserved microfloral assemblages where plant remains are the only constituents, with absence of indigenous marine organisms, have been successfully used by several authors as indicators of a continental environment.

Dijkstra (1949) remarked that the megaspores- and _Costatheca_-bearing Aachenian clays and sands of Limburg do not contain glauconite or shell fragments that are common constituents of the marine Hervenian intertongues. He therefore concludes that the sediments containing _Costatheca_ were deposited in a back-shore environment with dunes and shallow fresh-water ponds with very little transport of the microfossils.

Singh (1964) studied the microflora of the Mannville Group of Alberta, a succession of marine, brackish and continental beds of Early Cretaceous age. His tables 2, 3, 4, illustrating the microfloral distribution, clearly show that samples yielding abundant megaspores do not contain marine microplankton and conversely samples with abundant microplankton yield very few, if any, megaspores. Tschudy (1961) makes a strong point in favor of megaspores, and _Azolla_ in particular, as indicators of lacustrine and fluviatile environments. On page 58 he states:

> "_Azolla_, a modern fresh water fern, has been found in Tertiary lignites and shale. In our laboratory we have never encountered _Azolla_ in samples yielding an abundance of microforaminifers and dinoflagellates indicators of a brackish or marine depositional site. Should such a situation be encountered in the future, we have enough available data to permit the inference that probably a deltaic lake had been inundated by an advancing sea, causing a mixing of the organisms representing two facies types".

"White Sandstone" and Whitemud Formation

Azolla is probably the most important single environmental indicator of this assemblage. Megaspores of this lacustrine or pond fern are present throughout the examined interval. No vertical

variation of the abundance of Azolla has been noticed. It occurs as common or abundant up to the lithological contact with the Battle. This is most noticeable in the Cypress Hills sections where the Battle is underlain by claystones that yield a rich microflora, rather than in the sections from the Plains where in most cases a barren sandstone underlies the dark shales.

Most species of Spermatites (see Chapter Nine) are probably Cretaceous representatives of the extant genus Juncus, a "rush" that, although most common in fresh water environments like swamps, peaty or sandy margins of ponds and streams, is also frequently found on coastal plains, sea shores and other marginal marine realms. Therefore very little environmental indication can be obtained from the occurrence of Spermatites, at least until the relationships with the various species of Juncus are better understood.

Very little can be said of the other seed cuticles, with perhaps the exception of Carpotheca coronata that strongly resembles the seed of the extant genus Typha, a fresh to brackish water "cat-tail". Of the other megaspores, Minerisporites and Balmeisporites are often taken as fresh-water indicators (Tschudy, 1961; Hall, 1963), although the latter, a very small and easily floated megaspore, has also been recorded from marine sediments (Cookson and Dettmann, 1958).

Although no single element of the assemblage can be taken as absolutely certain proof of a fresh-water environment, the total assemblage, the abundance of plant microfossils and the fact that no marine organisms were found, are very convincing evidence to that effect.

The observation that the relative abundance of forms like _Azolla_ within a sample does not show any vertical variation in sections where the lithology allows such a control, indicates that no drastic changes of environment occurred in the studied interval. Only local variations from fluviatile to pond, swamp or lacustrine, as suggested by the grain size of the clastic sediments as a response to different energy levels, have occurred in the depositional environment of the interval underlying the Battle. The microfossils indicate that fresh water conditions were maintained throughout the whole interval.

Battle Member and Battle Formation

The environmental conditions under which the sediments of the Battle were deposited, differ from the ones that were present during the deposition of the underlying sediments. This difference is strongly reflected in the textural characters, the geometry of the deposit and in a slight change in the microfloral assemblage. The only microfossils present in this horizon are silicified megaspores, microspores, pollen, etc. Neither seed cuticles nor megaspores of _Azolla_ have been recovered from the dark shale. The fact that _Azolla_ and seed cuticles are definitely present both below and above the Battle and that records of silicified _Azolla_ (Sahni and Rao, 1943) are to be found in the literature, permits us to infer that the fossil remains might truly represent most of the flora living in place at the time of deposition. Abundance, frequency and preservation of the microfossils, together with the uniform grain size of the sediment over a

large area, give us enough confidence on the autocthony of the microfloral assemblage.

Most, if not all, of the megaspores present in this unit show a very strong affinity to megaspores of the extant genus Isoetes. Size, type of trilete mark and details of the ornamentation, all indicate such affinity. In 1753 Linnaeus (Species Plantarum, 2:1100) in the original definition of the genus wrote: "Habitat in Europae frigidae fundo lacuum". Pfeiffer (1922), in her extensive monograph, makes a series of remarks on the habitat of Isoetes. They can be summarized as follows:

1. All species of Isoetes are fresh-water. A previous record of a salt-water species (I. maritima) is discarded.
2. They can be divided into submersed amphibious and terrestrial forms, the latter mostly living on granitic mountain slopes.
3. Almost all the forms that live in water are associated with a type of sediment that indicates a low energy level, commonly mud. Only two forms are riparian.
4. A large number of species are common inhabitants of lakes, living submerged in six or more feet of water.

The micropaleontological data, especially if considered within the whole frame of the geological conditions strongly point toward an interpretation of a large fresh-water lake where, due to the high fall-out of volcanic ash at that particular time, only a primitive type of vegetal life represented by the quillwort*, and possibly spike-moss**

---

*Isoetes ** Selaginella

was possible. The hypothesis of a fresh-water lake, already advanced by Byrne (1951) is here supported on the basis of the micropaleontological findings.

CHAPTER EIGHT - INTERPRETATIVE SUMMARY

DEPOSITIONAL ENVIRONMENT

The Edmonton Formation as a whole represents a continental cycle of deposition following the withdrawal of the Campanian (Srivastava, 1968a) Bearpaw Sea, with only a minor marine incursion indicated by the Drumheller Marine Tongue. The lithologic assemblage of the Edmonton Formation (sandstones, siltstones, claystones, coal, and ironstones) is comparable with the sedimentary facies that the French authors call siderolitique (Millot, 1964) and that, according to Millot is the geological record of continental deposition of the humid intertropical zone. "Siderolitic" deposits can be found in many parts of the world throughout the geological column: in Europe the Carboniferous, the Wealden facies of the Lower Cretaceous, and the continental deposits of the Eocene of France, Germany and Czeckoslovakia belong to this type. The Upper Cretaceous of Gabon, the Tertiary of Dahomey and Togo, and parts of the Karroo and Kalahari "Systems" of Central and Southern Africa reflect the same type of depositional environment. Indications of climatic conditions of the intertropical zone throughout most of the Edmonton Formation are also to be found in the pollen assemblages studied by Srivastava (1968a).

At about the time of deposition of the sediments underlying the Battle Member and of the Battle itself a shift of climate towards more temperate conditions is suggested by Srivastava and can perhaps be supported by the affinity of the silicified megaspores of the Battle with the fresh-water fern Isoetes. Evidence for a fresh-water

depositional environment for the Battle Member/Formation and for the sediments underlying it, both in the Alberta Plains and in the Cypress Hills, are found in the micropaleontological and sedimentological findings of this thesis.

Megaspores and other land microfossils are the only remains that can be found in more than 200 samples of the Battle and underlying sediments from a large scatter of sampling locations in southern Alberta and in the westernmost corner of southern Saskatchewan.

Mechanical analyses of the sandstones underlying the Battle Member in southern Alberta indicate a fluviatile depositional environment comprising all the sub-facies that can be found in present-day rivers (Passega, 1957). The data on the clay minerals present in this part of the section are also in agreement with a fresh-water depositional environment, although it is not clear how reliable the clay minerals are as environmental indicators. Isotopic analyses of siderite spherulites and concretions in the sediments underlying the Battle yield δO^{18} values that are in agreement with δO^{18} values commonly accepted for fresh-water carbonates, whereas the δC^{13} values contrast with what has been suggested by Weber *et al*. (1964) to be indicative of fresh-water. These anomalous δC^{13} values must, however, be explained without having to invoke a marine environment since they occur throughout the Edmonton Formation.

It has been mentioned throughout this thesis that several authors have considered the Battle Member and the Battle Formation to be marine in origin. Since direct evidence for a marine origin is lacking and all reports of marine microfossils have been rather vague and

certainly not confirmed by this study, the strongest argument in favor of a marine origin has always been an indirect one. It has been argued that the Battle Member/Formation is continuous over too large an area to have been deposited in a continental milieu. The argument is that the continuity of the thin Kneehills Tuff bed within the dark claystone requires that the volcanic ash be deposited in water, as deposition of the volcanic ejecta on dry land where erosion was active, would not have led to preservation. Such a large body is indeed difficult to envisage.

Large bodies of fresh water with a rich vegetal life are certainly not abundant on the earth surface; they do, however, exist. Large swamps or temporary flood plains that can perhaps be suggested as modern analogues of the Battle environment are: the Sudd of southern Sudan in the high course of the Nile River, the Diamantina River-Cooper's Creek region of Eastern Australia, and the region of the lower course of the Tigris-Euphrates Rivers in Iraq. King (1967) reports that during time of heavy rains the alluvial plain of the Diamantina-Cooper's fluviatile system can be as wide as 50 miles and it has been said that Cooper's Creek can be 90 miles wide when in full flood. The confluence of the Bahr el Ghazal, White Nile, and Bahr ez Zeraf, in a basinal area of poor drainage, brings about the formation of a swamp (El Sudd) whose area is in the order of 40,000 square miles. Mud is deposited on the bottom, and a rich vegetal life of aquatic plants is present (King, _ibid_.). Extensive swamps ("Hors") are also to be found in the lower course of the Tigris and Euphrates, and it is especially the former that contributes exclusively mud in the last 200 kms of its course

(Philip, 1968). Other large bodies of fresh water in which continuous layers of clay have been recorded include the shallow Lake Chad, where the bottom is covered by bluish mud (King, 1967) and Lake Maracaibo. The latter, a fresh-water lake connected with the sea by the Straits of Maracaibo, shows a persistent layer of fine mud up to thirty meters thick, bearing continental fossils and underlain by silts, sands, and peat (Sarmiento and Kirby, 1962).

From the evidence which has been presented in the previous chapters, and from the comparison with present-day depositional environments we can then reconstruct the following succession of events in the depositional history of the Maestrichtian Stage of the Alberta Plains:

1. After the last marine incursion represented by the Drumheller Marine Tongue, a continental fluviatile depositional environment was re-established with rivers flowing possibly from the west and giving origin to channel, bar, flood plain, and backswamp-type deposits.
2. Basining and relatively poorer drainage conditions developed over an extensive area coinciding with a large amount of wind-blown volcanic ash and dust coming from the south during the time of the deposition of the Battle Member and Battle Formation. Wind-blown volcanic material was deposited in the swamp (or lake) throughout the deposition of the Battle, but it reached a peak during the time of deposition of the Kneehills Tuff bed, that is toward the end of "Battle time".
3. The fluviatile regime was re-established, probably within a relatively short time, either due to uplift in the source area or to other conditions that could have improved the drainage of the whole area. Evidence

of a higher energy level at the end of the time of deposition of the Battle can be found in the medium to coarse sandstones that overlie the dark claystone often cutting into the latter and giving origin to disconformities.

The reconstruction given above is still rather incomplete and certainly needs more detailed work, especially on the provenance of the sands and the tectonic setting. A careful mapping of the stream channels and floodplains in the top portion of the Middle Edmonton division should shed more light on the regional picture. The present work has given evidence for a continental origin of the Battle Member and Battle Formation and of the underlying sediments both in the Alberta Plains and in the Cypress Hills.

CORRELATION

The correlation of the dark brown claystone of the top of the middle division of the Edmonton Formation (Blackmud, Mauve Shale, Kneehills Tuff Horizon, Dark Zone) with the Battle Formation of the Cypress Hills, already suggested by a number of authors, is here confirmed by micropaleontological evidence. The two stratigraphic units bear microfossil assemblages that are virtually identical; they contain the same tuff bed; and they overlie sediments whose microfossil assemblages are identical from the Red Deer River Valley to the Cypress Hills.

The two stratigraphic units are not only synchronous, but they are also identical lithologically. They have the same clay minerals, and they show the same unusual type of preservation of the vegetal

microfossils. On these bases the adoption of the term Battle Member of the Edmonton Formation, used throughout this study, is not only justified but is recommended, and all other names should be dropped as unnecessary.

PROVENANCE OF THE KNEEHILLS TUFF

It has been shown in this study that the granulometric characteristics of the tuff bed indicate a provenance from the south, in agreement with mineralogical work by Ritchie (1957).

GRAIN SIZE ANALYSIS

The study of the grain size distribution of sandstones underlying the Battle Member has been useful not only in determining the depositional environment of the sandstones themselves, but also for comparing a number of methods aimed at the discrimination of sedimentary environments by mechanical analysis of sand. In this respect, the most important result has been that the discrimination between different sub-environments obtained by means of Passega's (1957) C-M diagrams is virtually the same as can be obtained using the more rigorous and comprehensive Q-factor analysis of Klovan (1966). This finding adds validity to the empirical C-M method and shows that the one percentile and median diameter contain enough information about the grain-size distribution to justify their use as criteria for environmental interpretation.

In the study of the Kneehills Tuff bed, a new statistical parameter, the coarse index (arithmetic mean of the 50 coarsest grains

visible in thin section) has been successfully employed in determining the provenance of the pyroclastic deposit.

VEGETAL MICROPALEONTOLOGY

A number of new form-genera and form-species of megaspores and cuticles have been described in this thesis.

The micropaleontological investigation has revealed that the Battle, previously believed barren or marine in origin, contains a rich terrestrial microflora that has been completely silicified. This is the first time that silicified megaspores with well preserved ornamentation have been isolated from shales and described at the specific level.

Among the cuticles that have been studied in this investigation, the genus *Spermatites* deserves particular mention. The comparison of species belonging to this genus with cuticles of modern seeds has shown affinity between *Spermatites* and the seed cuticles of the extant genus *Juncus*.

RECOMMENDATIONS FOR FURTHER STUDY

A better understanding of the pattern of sedimentation of the whole of the Edmonton Formation can only be reached through detailed small-scale studies of the sandstones and siltstones of this unit. Grain-size studies have been shown to be a useful tool for the detection of sub-environments within the general fluviatile depositional environment of the Edmonton and therefore the author feels that they should be emphasized. Studies of sedimentary structures should also be pursued.

The mode of formation of the ironstones of the Edmonton Formation deserves further investigation.

Only a very small part of the silicified microfossils of the Battle have been identified in this thesis. By far the largest portion, the silicified microspores, pollen grains, tracheids, etc., have barely been mentioned and not studied in any detail since this presents some technical problems. It is felt, however, that it might be possible to study and identify these remains if more sophisticated instruments such as the scanning electron microscope are employed.

CHAPTER NINE - TAXONOMY AND SYSTEMATICS*

MEGASPORES

Taxonomic Approach

The comparison of fossil megaspores with material already described is difficult as different techniques and practices are followed by different authors. Dijkstra (1949, 1951, 1959, 1961) and Vangerow (1954) study and describe their microfossils with the aid of a stereoscopic microscope under reflected light. Others prefer to use transmitted light, and for this it is necessary to make the fossils transparent by using nitric acid or Schulze solution. Obviously, comparisons between megaspores studied in these two different ways are difficult.

Different views are held by different authors with regard to nomenclature and classification. Three main types of approach can be distinguished.

1. Miner (1932 and 1935) described fossil megaspores from Greenland and Montana under the genus *Selaginellites*, a fossil type of obvious affinity with the extant genus *Selaginella*.

2. Dijkstra (*op. cit.*), Murray (1939), Hughes (1955), Vangerow (*op. cit.*), dealing with Mesozoic fossils, placed nearly all megaspores under the comprehensive genus *Triletes*.

---

*The exact stratigraphic position of types described herein can be found in Figure 18, page 124. The geographic location is given in Figure 3, page 14, and in Table I, page 15.

3. Potonié and Kremp (1954) and Potonié (1956, 1958) revised the genus _Triletes_ and created a number of genera based on spore morphology. This practice has been followed by a number of recent workers.

The problems of adopting a purely morphographic classification have been already mentioned by Singh (1964), the main drawback being its failure to take into account the known biolgical affinities. However, a more serious error creeps in by grouping all megaspores under the genus _Triletes_ as both taxonomic and stratigraphic implications are obscured.

The criteria for classification of megaspores followed here are the same as adopted by Singh (_ibid_.).

A place by itself is occupied by megaspores described under the genus _Azolla_. In this case we are dealing with fossils that can be attributed with a certain degree of certainty to an extant genus. Morphological criteria, however, are used to discriminate form-species within the extant genus.

Systematics

Genus TRILETES Reinsch, 1881, emended Schopf, 1938

Type species _Triletes reinschi_ (Ibrahim) Schopf, 1938

Diagnosis: Megaspores; radially symmetrical; equatorial outline more or less circular; proximal side marked by triradiate sutures or cracks separating three equal contact faces; arcuate ridges connecting the ends of the rays may be present in some species; distal

surface smooth or slightly granulate to rugulate, ornamentation generally less well developed on proximal than on distal surface; equatorial diameter exceeding 150 microns; usually very large, up to or more than 3 mm.

Triletes srivastavae sp. nov.

Plate I, figures 1, 2

Description: Megaspore trilete; equatorial outline sub-triangule with rounded sides; trilete mark raised, straight, 6 to 10 microns wide, extending up to the margin; thin arcuate ridges connecting the ends of the rays; exine almost smooth, ornamented with very small granulations about 1 micron in diameter.

Size: Spore diameter from 325 to 390 microns (holotype 372 microns).

Figured specimens: Figure 1: the holotype; locality: Ravenscrag Butte; level: Whitemud Formation; slide No. PB/T16/2. Figure 2: locality, level, and slide: same as holotype.

Remarks: The specific epithet has been given after Dr. S.K. Srivastava.

Genus MINERISPORITES Potonié 1956

1935 Selaginellites mirabilis Miner, Am. Midland Naturalist, vol. 16, p. 618, pl. 23, fig. 1.

1944 Triletes mirabilis (Miner) Schopf, Wilson and Bentall, Illinois Geol. Surv., Rept. of Invest. No. 41, Urbana, Ill., p. 1-61.

1956 Minerisporites mirabilis (Miner) Potonié, Beih. Geol. Jahrb., Heft 23, p. 67, pl. 9, figs. 87, 88 (type species).

<u>Diagnosis</u>: Trilete megaspores; equatorial outline of the central body subtriangular to almost circular; meridional outline of the central body semi-circular to circular; thin equatorial zona, widest at the apices, resulting in a triangular equatorial outline of the zone; triradiate lamellae (tecta) on the trilete laesurae extending onto the apices, up to the outer margin of the zona and strongly raised into a flap-like structure considerably higher than wide; exine thin, reticulate with vesicular lumina and curved muri (Singh, 1964, p. 157).

<u>Minerisporites</u> <u>mirabilis</u> (Miner) Potonié 1956

Plate I, figures 3-5

Synonymy as for genus

<u>Description</u>: Megaspore trilete, zonate; outline of the spore body circular; thin equatorial zona 60 to 70 microns wide at the apices and 10 to 20 microns wide in interradial regions, giving a subtriangular equatorial outline; trilete mark 30 to 40 microns high, extending up to the margin of the zona; exine thin, reticulate over the entire surface including zona; reticula rounded to polygonal; lumina 40 to 60 microns in diameter; muri 2 to 4 microns wide and 5 to 9 microns high.

<u>Size</u>: Spore diameter including zona from 326 to 410 microns, average 362 microns (10 specimens measured).

<u>Figured specimens</u>: Figure 3: locality: Red Deer River Valley, near Wood Lake; level: "White Sandstone", 4 m below contact with

Battle Member; slide No. PB/W9/2. Figures 4, 5: locality: Eastend; level: Whitemud Formation; slide No. PB/H30/7.

Remarks: The specimens of *M. mirabilis* described here are somewhat smaller in size than the ones recorded by Miner (1935) from the Upper Cretaceous of Montana and by Dijkstra (1961) from the Paleocene of South Dakota and the Netherlands. The smaller size is perhaps partially due to imperfect preservation and erosion of the outer zona, as can be seen in Plate I, figures 3 to 5.

Genus WARRENISPORITES gen. nov.

Type species *Warrenisporites spinosus* sp. et gen. nov.

Diagnosis: Trilete megaspores; equatorial outline of the central body subtriangular to circular; thin equatorial zona widest at the apices giving a subtriangular to triangular equatorial outline; trilete mark raised, higher than wide extending up to the margin of the zona; proximal face smooth or finely ornamented; distal face more heavily ornamented with coni, spines, knobs, ridges, etc.

Remarks: The genus *Warrenisporites* differs from *Triletes* Reinsch emended Schopf 1938, in having a well-defined zona. It can also be distinguished from *Stelckisporites* Binda and Srivastava 1968 by the raised trilete mark that does not show any splitting or commissures. The generic name has been given in honour of Dr. P.S. Warren, Professor Emeritus, University of Alberta, Edmonton.

Warrenisporites spinosus sp. nov.

Plate I, figures 6-10

Description: Megaspore trilete; zonate; outline of the central body circular to subtriangular; equatorial zona 80 to 120 microns wide at the apices and 20 to 70 microns wide in the interradial regions giving a subtriangular equatorial outline; trilete mark raised, 60 to 160 microns high becoming lower at the apices and at the intersection of the three rays, extending up to the margin of the zona; proximal face smooth to covered with fine granulation; distal face ornamented with straight or curved spines 20 to 40 microns wide at the base and 30 to 60 microns long, but often eroded to rounded coni.

Size: Spore diameter including zona from 390 to 520 microns (holotype 460 microns), average 437 microns (15 specimens measured).

Figured specimens: Figures 6, 9: the holotype; locality: Ravenscrag Butte; level: Whitemud Formation; slide No. PB/T24/33. Figure 7, 10: locality and level: same as holotype; slide No. PB/T24/16. Figure 8: locality and level: same; slide No. PB/T24/20.

Remarks: W. spinosus bears a certain resemblance to Triletes mirabilis (Miner) S., W. et B. forma glossoferus Dijkstra 1961. Size and shape are about the same and the protuberances on the distal surface are also very similar. The distal surface of W. spinosus is, however, almost smooth, while T. mirabilis forma glossoferus is reticulate.

Genus ERLANSONISPORITES Potonié 1956

1932 *Selaginellites erlansonii* Miner, J. Washington Acad. Sci., vol. 22, p. 500-501, fig. 1.

1956 *Erlansonisporites erlansonii* (Miner) Potonié, Beih. Geol. Jahrb., Heft 23, p. 46-47, pl. 5, fig. 53 (*type species*).

Diagnosis: Megaspores trilete; outline circular; the trilete mark completely covered by strong reticulations in some cases, thus being partially visible or not visible; muri on the reticulum transformed into thin and high membranous lamellae equally well developed all over the exine.

Remarks: The study of megaspores of the genus *Erlansonisporites* presents some technical difficulties. It is almost impossible to obtain specimens in which both lamellae and ornamentation of the spore-body are visible. A protracted oxidation destroys the lamellae whereas it makes the details of the ornamentation visible. One specimen (Pl. II, fig. 5) has been underoxidized in order to preserve the lamellae. As can be seen, the exine ornamentation is not visible.

Erlansonisporites singhii sp. nov.

Plate I, figures 11-13

Description: Trilete megaspore; outline circular; trilete mark raised, about 40 microns high, about 30 microns wide in plan view and extending about 2/3 of the spore radius; network of large reticulations; lumina round to irregularly polygonal, 40 to 100 microns wide, most often 60 microns; muri 6 to 10 microns wide at base, raised and transformed into membranous lamellae up to 50 microns high when

preserved and covering the whole spore; finer irregular reticulation present over the entire surface with lumina up to 6 microns in diameter and irregular muri at times not closed but forming vermiculate ridges up to 2 microns wide.

Size: Diameter of the spore, excluding the muri, from 310 to 520 microns (holotype 505 microns).

Figured specimens: Figures 11, 12: the holotype; locality: Quarry 45, near Elkwater; level: Whitemud Formation; slide No. PB/S38/2. Figure 13: locality and level: same as holotype; slide No. PB/S38/8.

Remarks: The above described megaspore differs from other species of *Erlansonisporites* in having a smaller reticulation inside the large one. The specific epithet is given in honour of Dr. C. Singh of the Research Council of Alberta.

Erlansonisporites augustus sp. nov.

Plate II, figures 1-4

Description: Trilete megaspore; outline circular or near circular; trilete mark raised and extending about 2/3 of the spore radius, but very often not visible due to the flattening of the spore; coarse network of irregular and large reticulations; lumina 50 to 150 microns in diameter; muri 15 to 30 microns wide at base, raised and transformed into membranous lamellae up to 100 microns high when preserved and covering the whole spore.

Size: Diameter of the spore, excluding the muri, from 497 to 1010 microns (holotype 1010 microns).

Figured specimens: Figures 1, 3: the holotype; locality: Red Deer River Valley, near Scollard; level: "White Sandstone", 7.5 m below contact with Battle Member; slide No. PB/M4/5. Figure 2: locality and level: same as holotype; slide No. PB/M4-5/5. Figure 4: locality: Scollard; level: "White Sandstone", 7.35 m below contact with Battle Member; slide No. PB/E2/2.

Remarks: *E. augustus* can easily be differentiated from other species of the same genus by its large size, its coarse and irregular reticulations and the height of the muri.

Genus HENRISPORITES Potonié 1956 emended

Binda and Srivastava 1968

Type species *Henrisporites affinis* (Dijkstra) Potonié 1956

Diagnosis: Megaspores trilete, zonate, amb subtriangular to triangular; tetrad mark reaching the equatorial outline of the zona, arms higher than their breadth, sometimes very high; proximal and distal surfaces with sparse granulate to spinate ornamentation.

Remarks: Potonié (1956) has described the genus *Henrisporites* as having sparse coni to spines and wrinkled exine. Binda and Srivastava (1968) emended the genus to include all zonate trilete megaspores having raised tetrad mark, granulate to spinate ornamentation and exine with or without wrinkles. The species described here under *Henrisporites* were established on silicified megaspores. The illustrated specimens are the type specimens of Binda and Srivastava (*ibid.*).

Henrisporites granulatus Binda and Srivastava 1968

Plate III, figures 1-6

Description: Megaspore trilete, plano-convex, zonate, zona 20 microns wide; tetrad mark prominently raised, arms of the tetrad mark 20 microns wide, extending to the equatorial outline of the zona, about 15 microns thick; amb subtriangular with convex sides; proximal surface smooth with concave interradial areas, distal surface granulate, granules 10 to 12 microns wide at the base.

Size: Equatorial diameter 275 to 380 microns, average 341 microns (25 specimens measured).

Figured specimens: Figures 1-3: the holotype; locality: Quarry 45, near Elkwater; level: Battle Formation; preparation No. BS2/31. Figures 4-6: locality and level: same as holotype; slide No. BS101.

Remarks: H. granulatus differs from other similar megaspores under the genus Henrisporites in having granulate ornamentation.

Henrisporites elkwaterensis Binda and Srivastava 1968

Plate III, figures 7-11

Description: Megaspore trilete, biconvex, zonate, zona 20 to 25 microns wide; tetrad mark prominently raised, extending up to the margin of the zona, arms of the tetrad mark about 40 microns wide; amb subrounded; proximal surface moderately verrucose, verrucae about 25 microns in diameter, on the distal surface verrucae are densely packed and often fused together to form a rugate pattern.

Size: Equatorial diameter 380 to 490 microns, average 432 microns (25 specimens measured).

Figured specimens: Figures 7-9: the holotype; locality: Quarry 45, near Elkwater; level: Battle Formation; preparation No. BS2/29. Figures 10, 11: locality and level: same as holotype; slide No. BS102.

Remarks: *H. elkwaterensis* is characterized by verrucose ornamentation and the size of the megaspore is larger than *H. granulatus*.

Henrisporites sheilae Binda and Srivastava 1968

Plate IV, figures 1-3

Description: Megaspore trilete, biconvex, zonate, zona about 15 microns wide; tetrad mark well defined and raised, extending up to the margin of the zona, arms of the tetrad mark 25 to 30 microns wide; amb subtriangular with convex sides; proximal and distal surfaces rugate, rugae 25 to 30 microns wide.

Size: Equatorial diameter 330 to 420 microns, average 375 microns (5 specimens measured).

Figured specimens: Figures 1-3: the holotype; locality: Standard; level: Battle Member of the Edmonton Formation; preparation No. BS1/33.

Remarks: *H. sheilae* is characterized by a tetrad mark extending up to the margin of the zona and by rugate ornamentation.

Genus VERRUTRILETES Van de Hammen 1954 ex potonié 1956

emended Binda and Srivastava 1968

1949 Triletes compositipunctatus Dijkstra, Mededel. Geol. Sticht., n.s., No. 3, p. 22, pl. 1, fig. 8.

1954 Verrutriletes Van der Hammen, Bot. Geol. (Bogota), vol. 2, p. 14.

1956 Verrutriletes compositipunctatus (Dijkstra) Potonié, Beih. Geol. Jahrb., Heft 23, p. 28, pl. 3, figs. 23-25 (type species).

Diagnosis: Megaspores trilete; equatorial and meridional outline circular to subtriangular; trilete rays may or may not reach the equator; ornamentation verrucose to conate; in some species verrucae fused at the base; proximal surface smooth or ornamented.

Remarks: The genus Verrutriletes was emended by Binda and Srivastava (1968) to include also verrucate trilete megaspores having tetrad mark that extends to the equatorial outline. Specimens described and illustrated here are also silicified and are the type specimens of Binda and Srivastava (ibid.).

Verrutriletes albertensis Binda and Srivastava 1968

Plate III, figures 12-14

Description: Megaspore trilete, biconvex with the higher convexity on the distal surface, tetrad mark well defined and raised, extending up to the equatorial margin, arms of the tetrad mark 25 microns wide; amb triangular with convex sides; proximal and distal surfaces densely verrucate, verrucae 10 to 12 microns wide at the base.

Size: Equatorial diameter 315 to 390 microns, average 365 microns (4 specimens measured).

Figured specimen: Figures 12-14: the holotype; locality: Standard; level: Battle Member of the Edmonton Formation; preparation No. BS1/31.

Remarks: The proximal and the distal surfaces of *V. albertensis* are densely verrucate and the tetrad mark extends up to the equatorial outline.

Genus HORSTISPORITES Potonié 1956

1951 *Triletes reticuliferus* Dijkstra, Mededel. Geol. Sticht., n.s., 5, p. 10, pl. 2, figs. 12, 13.

1956 *Horstisporites reticuliferus* (Dijkstra) Potonié, Beih. Geol. Jahrb., Heft 23, p. 44-45, pl. 5, fig. 51 (*type species*).

Diagnosis: Trilete megaspores; equatorial outline circular to slightly subtriangular, trilete mark about half the radius of the spore or longer, contact faces and arcuate ridges not distinguishable; entire exine alveolar or reticulate.

Remarks: The species of *Horstisporites* described here has been established on silicified material. The illustrated specimens are the type specimens of Binda and Srivastava (1968).

Horstisporites canadensis Binda and Srivastava 1968

Plate IV, figures 4-8

Description: Megaspore trilete, biconvex, proximal surface almost flattened; tetrad mark well defined and raised, extending up to the equatorial margin, arms of the tetrad mark about 35 microns wide; amb subrounded; proximal and distal surfaces reticulate, reticula large, muri 25 to 30 microns wide, lumina of 500 to 550 square microns in area.

Size: Equatorial diameter 550 to 710 microns, average 660 microns (25 specimens measured).

Figured specimens: Figures 4-6: the holotype; locality: Standard; level: Battle Member of the Edmonton Formation; preparation No. BS1/29. Figures 7, 8: locality and level: same as holotype; slide No. BS103.

Remarks: H. canadensis differs from H. reticuliferus (Dijkstra) Potonié, 1956, in having a raised tetrad mark that extends up to the margin and large reticulations with thick, well defined muri.

Genus STELCKISPORITES Binda and Srivastava 1968

Type species Stelckisporites standardensis Binda and Srivastava 1968

Diagnosis: Megaspore trilete, zonate, laesurae wide extending up to the margin of the zona, well defined labra on either side of the commissures; amb triangular to subtriangular with convex sides; exine surface heavily ornamented (granulate, verrucate, rugate, striate, reticulate, etc.), with ornamentation denser on the distal surface.

Remarks: Genus Stelckisporites differs from Triletes Reinsch emended Schopf, 1938, in having well defined zona and laesurae with well developed labra extending up to the margin of the zona. The elements of the ornamentation are always large, while the genus Triletes accommodates mostly smooth or slightly ornamented forms. The species described under this genus are based upon silicified material and the specimens illustrated here are the type specimens of Binda and Srivastava (1968).

<u>Stelckisporites</u> <u>standardensis</u> Binda and Srivastava 1968

Plate IV, figures 9-11; Plate V, figures 1, 2

<u>Description</u>: Megaspore trilete, biconvex with higher convexity on distal surface; zonate, zona about 40 to 50 microns wide; laesurae 25 microns wide, extending up to the margin of the zona, labra well developed, about 20 microns thick; amb triangular with convex sides; proximal surface sparsely verrucose, verrucae about 25 microns in diameter, sometimes two or three verrucae fuse to form rugate structures, distal surface densely verrucose, verrucae larger than 50 microns.

<u>Size</u>: Equatorial diameter 510 to 600 microns, average 580 microns (25 specimens measured).

<u>Figured specimens</u>: Plate IV, figures 9-11: the <u>holotype</u>; locality: Standard; level: Battle Member of the Edmonton Formation; preparation No. BS1/27. Plate V, figures 1, 2: locality and level: same as holotype; slide No. BS104.

<u>Stelckisporites</u> <u>tenuistriatus</u> Binda and Srivastava 1968

Plate V, figures 3-6

<u>Description</u>: Megaspore trilete, biconvex with higher convexity on distal surface; zonate, zona transparent about 40 microns wide; laesurae 20 to 25 microns wide; extending up to the margin of the zona, labra thin; amb subrounded with angular apices; proximal surface ornamented with thin ridges running both parallel and at an angle to the equatorial outline forming large reticulate pattern, with sparsely distributed knob-like structures, about 35 microns wide at the base;

distal surface with ridges running at an angle to the equatorial outline and ornamented with sparsely distributed knobs.

Size: Equatorial diameter 550 to 600 microns, average 570 microns (5 specimens measured).

Figured specimens: Figures 3-5: the holotype; locality: Standard; level: Battle Member of the Edmonton Formation; preparation No. BS1/35. Figure 6: locality and level: same as holotype; slide No. BS105.

Stelckisporites verrucosus Binda and Srivastava 1968

Plate V, figures 7-11

Description: Megaspore trilete, biconvex with higher convexity on distal surface; zonate, zona transparent, 50 microns wide; laesurae 25 to 30 microns wide, extending up to the margin of the zona, labra well developed about 15 microns thick; amb triangular with convex sides; proximal surface verrucose, verrucae about 50 microns wide at the base, distal surface more densely verrucate with the verrucae larger than on the proximal surface, verrucae studded side by side giving an appearance of a negative reticulate pattern.

Size: Equatorial diameter 510 to 650 microns, average 615 microns (25 specimens measured).

Figured specimens: Figures 7-9: the holotype; locality: Standard; level: Battle Member of the Edmonton Formation; preparation No. BS2/27. Figures 10, 11: locality and level: same as holotype; slide No. BS106.

Genus SELENASPORITES Binda and Srivastava 1968

Type species Selenasporites reticulatus Binda and Srivastava 1968

Diagnosis: Megaspore without tetrad mark or lete, globular to oval in shape, ornamentation reticulate.

Remarks: The species described here was established on silicified material. The illustrated specimen is the holotype of Binda and Srivastava (1968).

Selenasporites reticulatus Binda and Srivastava 1968

Plate V, figure 12

Description: Megaspore without tetrad mark, biconvex; amb circular to ovate; ornamentation reticulate, muri about 15 microns wide; lumina up to 400 square microns in area.

Size: Equatorial diameter 370 to 450 microns, average 425 microns (25 specimens measured).

Figured specimen: Figure 12: the holotype; locality: Red Deer River Valley, near Scollard; level: Battle Member of the Edmonton Formation; preparation No. BS2/35.

Genus BALMEISPORITES Cookson and Dettmann 1958

Type species Balmeisporites holodictyus Cookson and Dettmann 1958

Diagnosis: "Megaspore" consisting of a spherical body, 70 to 135 microns in equatorial diameter, with three equidistant reticulate equatorial outgrowths of the exoexine and a more prominent neck at the proximal pole composed of three united leaf-like segments, which surround the tetrad scar.

Remarks: In the original diagnosis, Cookson and Dettmann (1958) emphasized the presence of "three equidistant reticulate equatorial outgrowths of the exoexine". B. auriculatus Hall, 1963 bears three auriculate equatorial extensions. The species of Balmeisporites described by Kondinskaya (1966) do not show any such "equatorial outgrowths" but the exospore extends below the equator covering the whole spore-body. Srivastava and Binda (1969) have already remarked that the "equatorial outgrowths" should be considered a specific character and not diagnostic at a generic level.

The terms exospore for the spore covering and acrolamellae for the leaf-like segments are here adopted following Srivastava and Binda (ibid.).

The size-range given in the original diagnosis of the genus Balmeisporites should be extended to include the megaspores described here that were all collected on a 149 microns sieve and range up to 200 microns.

Recorded occurrence of the genus Balmeisporites:

Australia and New Guinea, from Lower and Upper Cretaceous sediments (Cookson and Dettmann, 1958): B. holodictyus, B. tridictyus, B. glenelgensis.

Iowa, U.S.A., from the Dakota Formation of Cenomanian age (Hall, 1963): B. auriculatus.

Bryan County, Oklahoma, U.S.A., from the Red Branch Member of the Woodbine Formation of Cenomanian age (Hedlund, 1966): B. glenelgensis.

West Siberian Lowland, U.S.S.R., from Senonian sediments (Kondinskaya, 1966): *B. diversispinulatus*, *B. rarus*, *B. granulatus*, *B. striatellus*, *B. longirimosus*, *B. bellus*, *B. mollis*.

Alberta and Saskatchewan, Canada, from the Edmonton Formation, Late Campanian-Maestrichtian and the Whitemud Formation, Maestrichtian (Srivastava and Binda, 1969): *B. bellus*, *B. canadensis*, *B. kondinskayae*, *B. dettmannii*. Of these four species only the last does not appear among the fossils described in the present study. The type specimens of the above mentioned species are the ones illustrated here.

Balmeisporites bellus Kondinskaya 1966

Plate VII, figures 1-3

Description: Trilete megaspore; spore-body circular in outline, covered by double-layered exospore; inner layer of exospore formed by ribbon-shaped structures criss-crossing on several levels to form complex reticulate network, converging and fusing at places to produce large conical protrusions; ribbons 5 to 6 microns wide, pitted in the center, diameter of pits 1 to 2.5 microns; outer layer irregularly and finely reticulate; acrolamellae three, proximal, formed by outer layer of exospore.

Size: Diameter of spore body 125 to 180 microns; length of acrolamellae 80 to 120 microns.

Figured specimens: Figures 1-3: locality: Quarry 45, near Elkwater; level: Whitemud Formation; slide No. PB/S38/1.

Remarks: The specimens described in the present study fit the description given by Kondinskaya (1966) but are larger in size.

Norton and Hall (1967) designated the new megaspore genus Styx, with two species, S. minor and S. major, from the Upper Cretaceous Hell Creek Formation of eastern Montana. The two species described on pages 104 and 105, and illustrated as figures B and C of plate I of Norton and Hall seem to lack acrolamellae, but have the characteristic structure, ornamentation, and size of B. bellus. At the present time there is not sufficient information to treat the genus Styx as a synonym of B. bellus, but there is a strong possibility that this might be the case.

Balmeisporites canadensis Srivastava and Binda 1969

Plate VII, figures 4-6

Description: Trilete megaspore; spore-body circular in outline, covered by double-layered exospore; inner layer of exospore verrucate; verrucae 6 to 10 microns in diameter, densely packed, showing irregular negative reticulum on surface; outer layer thin, reticulate; lumina 8 to 10 microns wide; muri not raised, about 2 microns wide; acrolamellae three, proximal; conical appendages around rest of the body; acrolamellae and appendages formed by outer layer of exospore.

Size: Diameter of spore-body 180 to 200 microns, length of acrolamellae 80 to 100 microns, length of conical appendages 40 to 90 microns.

Figured specimen: Figures 4-6: the holotype; locality: Red Deer River Valley, near Scollard; level: "White Sandstone", 7.5 m below contact with Battle Member; slide No. PB/M5/3.

Remarks: B. canadensis differs from other species in having a verrucate inner layer of exospore and larger reticulations on the thin outer layer.

Balmeisporites kondinskayae Srivastava and Binda 1969

Plate VII, figure 7

Description: Trilete megaspore; spore-body circular in outline, covered by double-layered exospore; inner layer of exospore formed by parallel ribbon-shaped structures; ribbons 4 to 5 microns wide, with smooth edges and 2.5 microns wide punctate central band; outer layer thin (3 to 4 microns), with fine irregular reticulations (1 to 1.5 microns wide); large, irregular reticulation formed by exospore; lumina 28 microns wide, muri sinuous, braided in appearance, 10 microns wide and 25 microns high; acrolamellae three, proximal, formed by outer layer of exospore.

Size: Diameter of spore-body 130 to 180 microns; length of acrolamellae 92 to 135 microns.

Figured specimen: Figure 7: the holotype; locality: Eastend; level: Whitemud Formation; slide No. PB/H30/1.

Remarks: The ribbon-shaped structures of the exospore of B. kondinskayae do not criss-cross, fusing into conical protrusions like in B. bellus. In B. kondinskayae the ribbons run more or less side by side, rising high to form muri of the large reticulations.

<u>Balmeisporites</u> <u>densireticulatus</u> sp. nov.

Plate VII, figures 8, 9; Plate VIII, figures 1, 2

<u>Description</u>: Trilete megaspore; spore-body circular in outline; covered by an exospore finely folded to form an irregular reticulation with raised muri and spine-like protrusions 20 to 30 microns long and 6 to 8 microns wide at base; lumina irregular in shape, 6 to 12 microns in diameter; muri sinuous, 2 to 5 microns wide; acrolamellae three, proximal, displaying the same type of reticulation present on the spore body.

<u>Size</u>: Diameter of spore-body 145 to 195 microns (holotype 185 microns); length of acrolamellae 120 to 155 microns (holotype 145 microns).

<u>Figured specimen</u>: Plate VII, figures 8, 9, Plate VIII, figures 1, 2: the <u>holotype</u>; locality: Ravenscrag Butte; level: Whitemud Formation; slide No. PB/T16/2.

<u>Remarks</u>: <u>B.</u> <u>densireticulatus</u> is easily recognizable by its fine and dense irregular reticulations.

<u>Balmeisporites</u> sp.

Plate VIII, figures 3, 4

<u>Description</u>: Trilete megaspore; spore-body circular in outline; covered by exospore with large irregular reticulations; lumina 25 to 35 microns wide; muri 4 to 5 microns wide, raised at junctions to form irregular spines and protrusions; acrolamellae three, proximal, formed by the exospore and probably forming wing-like equatorial outgrowths.

Size: Diameter of the spore-body 197 microns; length of acrolamellae 125 microns.

Figured specimen: Figures 3, 4; locality: Red Deer River Valley, east of Delburne; level: "White Sandstone", 4.5 m below contact with Battle Member; slide No. PB/β16/3.

Remarks: Only one specimen of this type was found, therefore it has not been given a specific epithet. It appears to be a species distinct from forms previously described, although it could be related to B. glenelgensis Cookson and Dettmann, 1958.

Megaspore type A

Plate VIII, figures 5, 8

Description: Trilete megaspore showing a hemispherical spore-body of approximately 300 microns in diameter, surrounded by an exospore bearing appendages and forming a number of proximal extensions; appendages on the acrolamellae 50 to 60 microns long and 25 microns wide at base, becoming narrower at about mid-length and terminating in rounded "pin-heads" 20 to 30 microns wide; club-shaped appendages up to 100 microns long and 50 microns wide at the distal end. Length, including appendages, 735 microns.

Figured specimen: Figures 5, 8; locality: Quarry 45, near Elkwater; level: Whitemud Formation; slide No. PB/S14/1.

Remarks: The above described microfossil resembles Arcellites (Pyrobolospora) vectis Hughes 1955, a megaspore reported from the Wealdian of the Isle of Wight, Britain. However, since the only individual found here is poorly preserved, no certain attribution is possible.

Megaspore type B

Plate VIII, figures 6, 7

Description: Megaspore with a dark coating masking the spore-body; lamellae not distinct; club-shaped appendages surrounding the whole microfossil, 100 to 120 microns long and 40 to 50 microns wide. Length, including appendages, 850 microns.

Figured specimen: Figures 6, 7: locality: Quarry 45, near Elkwater; level: Whitemud Formation; slide No. PB/S38/B.

Remarks: The above described specimen seems to differ from Megaspore type A by the shape of the appendages. Since the only individual found is poorly preserved, no certain attribution is possible.

Family SALVINIACEAE

Genus AZOLLA Lamark, 1783

A number of megaspores attributable to fossil species of the water fern Azolla Lamark were encountered in the microfossil assemblage of the Whitemud Formation and "White Sandstone" and underlying beds of the Edmonton Formation. Fossil remains of Azolla, both vegetative and reproductive, have been described by several authors, especially from Tertiary and Quaternary deposits, with a few recorded occurrences from the Upper Cretaceous. A fairly comprehensive, although not complete, list of species described in the paleontological literature is given by Hills and Weiner (1965). The Cretaceous forms are A. geneseana Hills and Weiner, 1965, and A. cretacea Stanley, 1965, the latter also reported by Srivastava (1966), and Norton and Hall (1967). Srivastava (1968d) described five species of Azolla from the

Edmonton Formation. Two of these were the new species A. hamata and A. sagittifera. All these Cretaceous forms were described from the Maestrichtian of North America. The reproductive remains usually found consist of megaspores coated in their perispore involucre sometimes bearing floats, massulae containing the microspores, and isolated microspores. While the isolated microspores are not deemed to be of any use for classification purposes, massulae and floats have been mainly used by various authors as discriminatory criteria at the specific level. Mahabalé (1963) based his evolutionary theory of the genus Azolla on the type of glochidia borne by the massulae. Glochidia are also used by Stanley (1965), Hills and Weiner (1965) and other authors. Dorofeev (1959) gives utmost significance to number, size and shape of the floats.

Although of great importance in order to establish relationships with extant types, floats and massulae are of limited use to a micro-paleontologist working with megaspores. Floats can become detached from the megaspore complex during the treatment of the sample and it is very rare to find fossil megaspores that still bear the original number of such structures. Massulae and megaspores are separate bodies and if one sample yields more than one type of megaspore and more than one type of massula, it is impossible to correlate between the two types of reproductive remains.

Criteria analogous to the ones used in dealing with any other type of megaspores should therefore be used for Azolla. Snead (1969) suggests that differences in ornamentation of the perispore wall should

be the discriminatory criterion at the specific level. A similar morphologic approach is followed here, and the type of perispore wall, together with shape and size of the "megaspore complex" is used for classification purposes. This leads to the creation of fossil form-species within the natural genus Azolla Lamark based purely on the "megaspore complex". In order to avoid the confusion that would arise from the creation of a riddle of new names, among which a great many would be synonyms of forms already described, no formal specific epithets are used here. A, B, C etc. will, for the time being, designate the species described.

Azolla sp. A

Plate IX, figures 1-3

Description: "Megaspore complex" consisting of a trilete megaspore-body enclosed by an involucre consisting of a spherical perispore, a "swimming apparatus" and a hairy layer covering the whole structure; perispore proper 20 to 35 microns thick, maximum thickness at proximal end, with smooth, unornamented surface; "swimming apparatus" generally rounded at top but displaying some "flame-like" terminations; hairy cover particularly thick in distal region and around the upper part of the perispore proper, up to 40 to 50 microns; hair sometimes giving the appearance of reticulate or striate ornamentation; individual fibrils up to 2.5 microns in diameter, often terminating in a round, closed curl of 5 to 9 microns in diameter; megaspore body often not visible under the thick cover.

Size: Total length 643 to 1094 microns, average 903 microns (10 specimens measured). Maximum width of the "swimming apparatus" 382 to 650 microns, average 539 microns. Diameter of spore plus perispore 321 to 430 microns, average 420 microns.

Figured specimens: Figure 1: locality: Quarry 45, near Elkwater; level: Whitemud Formation; slide No. PB/S14/13. Figures 2, 3: locality: Ravenscrag Butte; level: Whitemud Formation; slide No. PB/T24/30.

Remarks: *A.* sp. A bears striking resemblance to *A. filosa* Snead 1969 and it should probably be attributed to the same species. It must be noted that Snead uses the notation "outer lamella of the perispore" for the hairy mat that is here interpreted as a cover of the perispore *sensu stricto*.

Azolla sp. B

Plate IX, figures 4-6

Description: "Megaspore complex" consisting of a trilete megaspore-body enclosed by an involucre composed of a double-layered perispore nearly spherical in shape bearing a conical "swimming apparatus" and of a continuous hairy mat 6 to 12 microns thick covering the whole structure; outer layer of perispore 8 to 12 microns thick and irregularly reticulate; muri 3 to 3.5 microns wide at base becoming larger at top; lumina rounded to triangular to elongate, maximum diameter approximately 8 microns (in lower focus); bulbous protuberances, often pitted, present sometimes at junction of muri; inner layer

of perispore 3 to 5 microns thick, finely granulate to smooth and hardly distinguishable; in some specimens cap showing a spongy texture with circular holes 4 to 8 microns in diameter; megaspore body often folded or crumpled and lying at bottom of receptacle provided by perispore.

Size: Total length 337 to 574 microns, average 506 microns (10 specimens measured). Maximum width 306 to 398 microns, average 368 microns. Diameter of spore plus perispore 282 to 371 microns, average 330 microns.

Figured specimens: Figures 4, 5: locality: Quarry 45, near Elkwater; level: Whitemud Formation; slide No. PB/S14/10. Figure 6: locality and level: same as above; slide No. PB/S14/11.

Remarks: *A.* sp. B resembles *A. distincta* Snead 1969 in the reticulate ornamentation of the outer perispore. *A. distincta*, however, has a fine reticulation of the inner perispore that was not observed in any specimens of *A.* sp. B. The two species are, however, very closely related.

Azolla sp. C

Plate IX, figures 7-9

Description: "Megaspore complex" consisting of a trilete megaspore-body enclosed by an involucre composed of a double-layered perispore nearly spherical in shape bearing a "swimming apparatus" of diaphanous matter and of a continuous hairy mat 6 to 15 microns thick

covering the whole structure; outer layer of perispore about 12 microns thick; foveoreticulate; muri 3 to 6 microns wide at base becoming larger at top giving origin in some cases to tectate sculpture; lumina of the few true reticula up to 5 microns in diameter, but more often consisting of narrow slits up to 10 microns long of the typical foveolate ornamentation; inner layer of perispore 3 to 5 microns thick, finely granulate to smooth and hardly distinguishable; cap covered by a fine reticulation produced by the fibrils of the outer layer; megaspore body barely visible under the thick perispore.

Size: Total length 532 to 555 microns (only 3 specimens measurable). Maximum width 398 to 444 microns. Width of spore plus perispore 337 to 380 microns.

Figured specimen: Figures 7-9: locality: Quarry 45, near Elkwater; level: Whitemud Formation; slide No. PB/S14/10.

Remarks: The foveoreticulate outer perispore of *A.* sp. C is identical to the one of *A. barbata* Snead 1969. The latter, however, lacks the outer hairy layer. *A.* sp. C is very similar to *A.* sp. B from which it differs only in the foveoreticulate ornamentation of the outer perispore. Thus the negative areas are reduced in size with respect to *A.* sp. B. Specimens of *A.* sp. C are fairly rare in the studied material.

Azolla sp. D

Plate X, figures 1-4

Description: "Megaspore complex" consisting of a trilete megaspore-body enclosed by an involucre composed of a double-layered perispore, nearly spherical to pear-shaped bearing a "swimming apparatus" of diaphanous, almost gelatinous matter; outer layer of perispore 10 to 12 microns thick, ornamented with broad verrucae, 10 to 20 microns wide, very closely spaced and often fused together to form elongated ridges or rounded atoll-like "islands" 30 to 40 microns in diameter with a 5 microns fovea in the center; incomplete negative reticulations in the low areas between verrucae with development of foveae at the junction of the elongated depressions; inner layer 8 to 10 microns thick, ornamented with small verrucae to rugulae up to 3 microns in diameter; megaspore body often folded or crumpled and sometimes not visible under the thick perispore.

Size: Total length 535 to 612 microns, average 568 microns (10 specimens measured). Maximum width of swimming apparatus 352 to 428 microns, average 397 microns. Diameter of spore plus perispore 337 to 371 microns, average 349 microns.

Figured specimen: Figures 1-4: locality: Quarry 45, near Elkwater; level: Whitemud Formation; slide No. PB/S14/11.

Remarks: Azolla sp. D differs from the other species in the incomplete negative reticulation that represents a further reduction of the negative areas of A. sp. C.

<u>*Azolla*</u> sp. E

Plate X, figures 5-7

<u>Description</u>: "Megaspore complex" consisting of a trilete megaspore-body enclosed by an involucre composed of a double-layered perispore nearly spherical to pear-shaped bearing a "swimming apparatus" of diaphanous matter; both perispore and "swimming apparatus" covered by a hairy mat; hairy layer up to 20 microns thick, maximum thickness usually found around the perispore and especially in distal area; fibrils of hairy layer often arranged in such a way as to give appearance of reticulate ornamentation; outer layer of perispore proper 8 to 10 microns thick, finely vermiculate to reticulate and showing several small pores, circular to irregularly elongate in outline; inner layer of perispore smooth to finely punctate; a few structures (floats?) circular in outline, 45 to 50 microns in diameter, present in some cases on the perispore just below the "swimming apparatus"; trilete megaspore with smooth to finely punctate wall usually visible folded at bottom of receptacle.

<u>Size</u>: Total length 444 to 605 microns, average 543 microns (10 specimens measured). Maximum width of cap 329 to 367 microns, average 349 microns. Diameter of spore plus perispore 275 to 306 microns, average 295 microns.

<u>Figured specimen</u>: Figures 5-7: locality: Quarry 45, near Elkwater; level: Whitemud Formation; slide No. PB/S14/10.

<u>Azolla</u> sp. F

Plate X, figures 8-10

<u>Description</u>: "Megaspore complex" consisting of a trilete megaspore enclosed by a double-layered spherical perispore completely surrounded in its turn by a very thick, hairy oblong involucre; "swimming apparatus" absent or poorly preserved in most speciments; outer layer of perispore proper ornamented with large reticulation and up to 15 microns thick when measured at muri, 3 microns thick when measured at lumina; lumina polygonal, irregular in shape, up to 30 to 40 microns in diameter; muri 5 to 10 microns wide at base, tapering at top and margin without a clear separation into the fuzzy, hairy layer 30 to 40 microns thick in distal region; innermost layer of perispore 5 microns thick and smooth; trilete megaspore, usually folded, visible inside the receptacle.

<u>Size</u>: Total length 467 to 535 microns (only 4 specimens measured). Maximum width 291 to 398 microns. Diameter of spore plus perispore 237 to 314 microns.

<u>Figured specimen</u>: Figures 8-10: locality: Quarry 45, near Elkwater; level: Whitemud Formation; slide No. PB/S38/6.

<u>Azolla</u> sp. G

Plate X, figures 11, 12

<u>Description</u>: "Megaspore complex" consisting of a trilete megaspore enclosed by a nearly spherical perispore completely surrounded by a thick, hairy, flask-shaped involucre; perispore proper 15 to 20 microns thick, smooth and apparently single-layered; outer

involucre showing hairy to gelatinous knobs 30 to 40 microns in diameter; megaspore body hardly visible under the thick cover.

Size: Total length 482 to 505 microns (only 3 specimens measurable). Maximum width 275 to 344 microns. Diameter of spore plus perispore 199 to 291 microns.

Figured specimen: Figures 11, 12: locality: Nevis Bridge; level: "White Sandstone", 1.30 m below contact with the Battle Member; slide No. PB/U14/1.

SEED CUTICLES

Taxonomic Approach

Under this group are described vegetal microfossils whose affinities lie with cuticles of seeds, although in most cases no definite relationship with extant genera can be demonstrated.

Morphological criteria have here been adopted in an attempt to classify such plant remains along the lines of previous works by Miner (1935), Dijkstra (1949), Schemel (1950), Vangerow (1954), and others. However, the natural affinities of a few types have been investigated and discussed when possible in order to give a meaningful panorama of the floral assemblage of the horizons under study.

The criteria used to discriminate genera and species are the following:

(1) At the generic level. The presence or absence of regular plications or ribs has been applied in conjunction with the general type of wall structure. The shape of the wall cells has been used as follows:

Spermatites: cells more or less equilateral.

Costatheca: cells elongated perpendicular to the long axis of the body.

Carpotheca: cells elongated parallel to the long axis of the body.

(2) *At the specific level*. Finer discriminatory characters have been used such as shape, details of the ornamentation, size range and the ratio between length and width (abbreviated in the text to L/W). For this purpose diagrams were constructed plotting length in microns on the scale of the abscissae and L/W ratio on the scale of the ordinates. In these diagrams the data given by Miner (*op. cit.*) and Vangerow (*op. cit.*) were plotted. Since Miner in the descriptions of his species of *Spermatites* did not give the ranges of the L/W ratios, averages had to be calculated from the average lengths and widths of his specimens. Miner's data therefore plot as straight, horizontal lines representing the horizontal ranges and the vertical centers of ideal fields. From Vangerow's data such fields could be directly constructed. They are, however, maximal fields, since the complete set of measurements was not available. Measurements of well-preserved specimens of the microfossils described in the present study were subsequently plotted and compared in the already described species (Figs. 19 and 20).

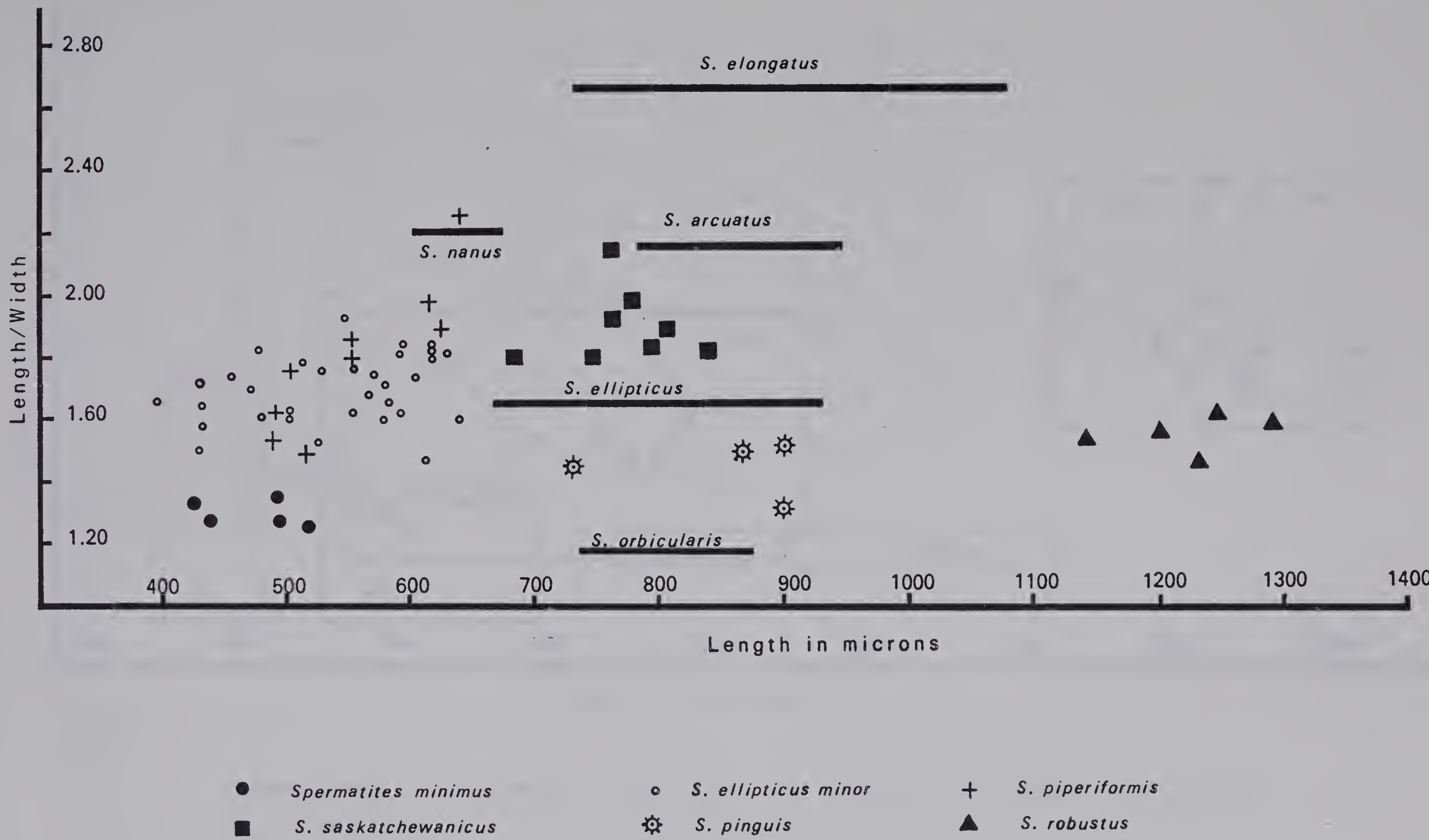


FIGURE 19

Plot of length versus length-to-width ratio of Spermatites from the Edmonton and Whitemud Formations. Solid bars represent limits of species described by Miner (1935).

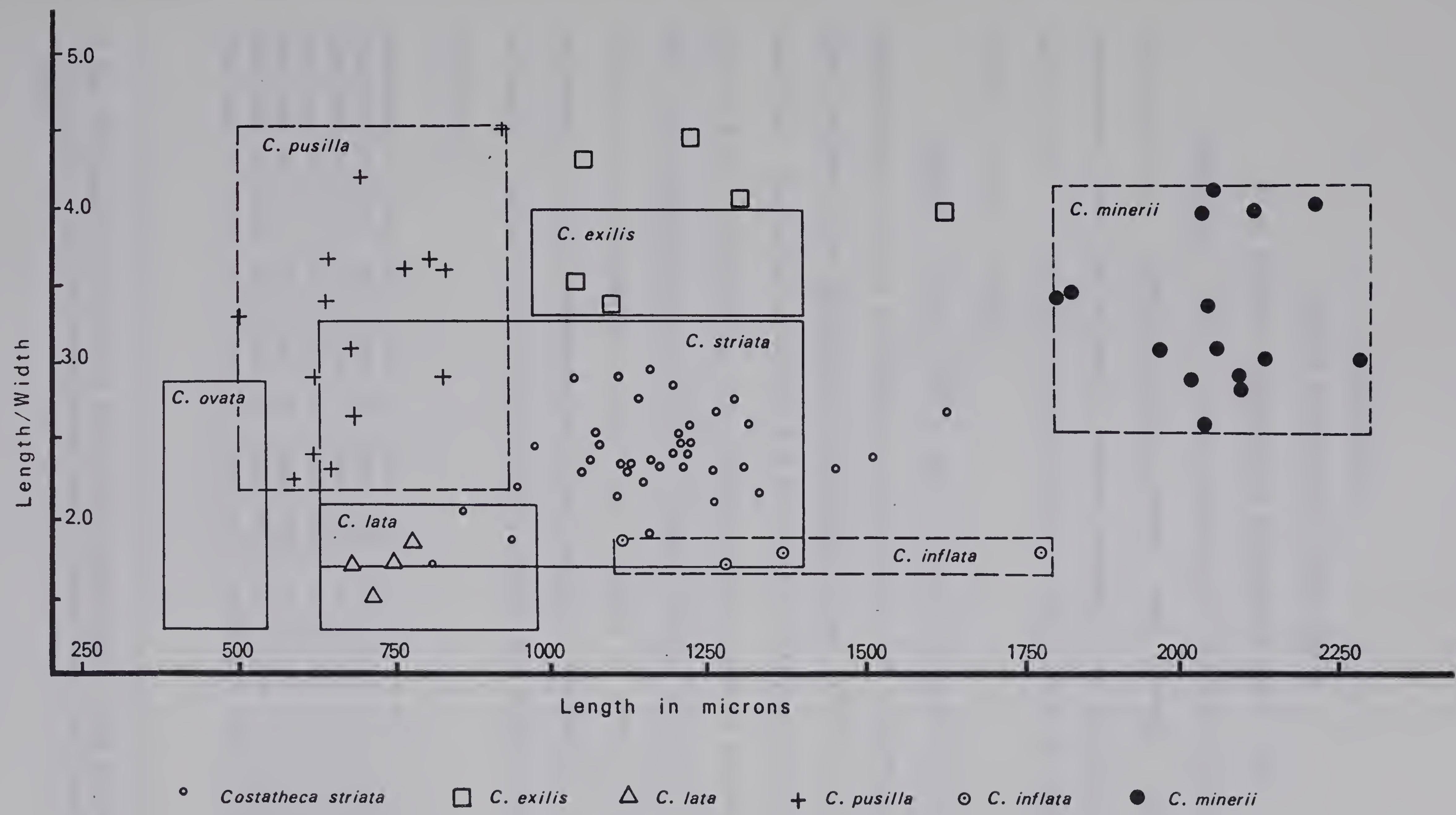


FIGURE 20

Plot of length versus length-to-width ratio of Costatheca from the Edmonton and Whitemud Formations. Solid-line rectangles represent fields constructed using limits given by Vangerow (1954). Dashed-lined rectangles represent fields of new species.

Systematics

Genus SPERMATITES Miner 1935*

Type species *Spermatites ellipticus* Miner 1935

Diagnosis: Small, hollow structures varying considerably in size and shape, oblong-elliptical, ovate, oval, obovate, orbicular or phaseoloid; wall cells small, square, hexagonal or rectangular; orifice small, apical or slightly lateral; base a dense mass of compact cells, sessile or short stalked.

Remarks: Miner (1935), while describing seven species of *Spermatites*, did not designate a type species for the genus. It is here proposed that *Spermatites ellipticus* Miner, 1935 be elected as genotype. Furthermore, Miner did not select holotypes for his species. The need for establishing type species and lectotypes arises from the fact that *Spermatites* as defined by Miner (1935), with its very definite characteristics, seems to be a fossil of some stratigraphic importance in the Cretaceous of North America. Therefore, the following specimens described by Miner (1935) are hereby chosen as lectotypes.

Specimen of fig. 28, plate 18, page 607, lectotype of *S. orbicularis*
Specimen of fig. 29, plate 19, page 609, lectotype of *S. elongatus*
Specimen of fig. 39, plate 19, page 609, lectotype of *S. ovatus*
Specimen of fig. 46, plate 19, page 609, lectotype of *S. ellipticus*
Specimen of fig. 49, plate 19, page 609, lectotype of *S. arcuatus*
Specimen of fig. 53, plate 19, page 609, lectotype of *S. nanus*
Specimen of fig. 56, plate 20, page 611, lectotype of *S. pylophorus*

---

* The discussion concerning the genus *Spermatites*, and the description of two species and one subspecies have already been published (Binda, 1968).

Schemel (1950) has already shown the opportunity of restricting the use of the generic name Spermatites "to include only those plant microfossils which show convincing evidence of their affinity to the specimens upon which Miner (1935) based his generic diagnosis". Following these criteria, the three species described by Arnold (1948) from Lower Pennsylvanian coals of southern Michigan and the species described by Hughes (1961) from the Lower Cretaceous of England are not treated here as Spermatites, since Arnold includes in this genus "any unassigned seeds or ovules for which no suitable name exists" and Hughes uses the generic name Spermatites for "seeds (or parts of seeds) as seen after maceration, in transmitted light".

Recorded Distribution of the Genus Spermatites

-- Disko Island and Nugsuak Peninsula, Greenland, from Upper Cretaceous coals (Miner, 1935).

-- Plymouth County, Iowa, from coals of the Dakota Formation, Cenomanian age (Schemel, 1950 and Hall, 1963).

-- Bryan County, Oklahoma from the Red Branch Member of the Woodbine Formation of Late Cretaceous age (Hedlund, 1966).

-- Charente-Maritime, France, Albian-lower Cenomanian (Deák and Combaz, 1967).

-- Alberta and Saskatchewan (Binda, 1968; some material of the present thesis).

Spermatites piperiformis Binda 1968

Plate XI, figures 1-3

Description: Shape curved with one side convex and one concave or straight; length 486 to 640 microns, average 554 microns; width 283 to 344 microns, average 307 microns; L/W ratio 1.50 to 2.27, average 1.81; maximum width close to the base; base rounded or sometimes concave with a short stalk; apex tapering to an acuminate end with a dark dense mass of compact cells; wall cells square, rectangular or hexagonal, arranged in longitudinal rows, average size of cells 30 x 23 microns; a transparent outer layer covering the cuticle present in well preserved specimens.

Figured specimens: Figures 1, 2: the holotype; locality: Standard; level: "White Sandstone", 2.5 m below contact with the Battle Member; slide No. PB/P1/3. Figure 3: locality: Standard; level: "White Sandstone", 4.5 m below contact with the Battle Member; slide No. PB/Q3/9.

Remarks: S. piperiformis differs from other forms of the same genus in being curved. It is somewhat similar to S. arcuatus Miner 1935 but is smaller in size and the base is pointed instead of obtuse. S. piperiformis, although fairly common, is not too abundant.

Spermatites minimus Binda 1968

Plate XI, figures 5-7

Description: Shape almost orbicular to elliptical with sides strongly convex; length 418 to 517 microns, average 470; width 320 to 406 microns, average 359; L/W ratio 1.27 to 1.38, average 1.31; maximum

width at or near mid-part; base rounded, often with a short stalk; apex slightly tapering with a dark dense mass of compact cells; wall cells rectangular, pentagonal or hexagonal, arranged in longitudinal rows, average size of cells 30 x 22 microns; a transparent outer layer covering the cuticle present in well preserved specimens.

Figured specimens: Figures 5, 6: the holotype; locality: Standard; level: "White Sandstone", 4.5 m below contact with the Battle Member; slide No. PB/Q3/8. Figure 7: locality, level, and slide: same as holotype.

Remarks: *S. minimus* differs from other species of the same genus in having small size and low L/W ratio as it is shown in Figure 19. It is fairly rare and the number of individuals measured and plotted in the diagram is low, but many specimens, undoubtedly belonging to *S. minimus*, were not measured because they were folded.

Spermatites ellipticus Miner 1935 subspecies *minor* Binda 1968

Plate XI, figures 9-11

Description: Shape elliptical to oblong with convex sides; length 394 to 640 microns, average 535 microns; width 234 to 394 microns, average 312 microns; L/W ratio 1.47 to 1.95, average 1.72; maximum width at mid-part or near base; base rounded with a short stalk; base very often broken open; apex tapering to an acute end with a dark dense mass of compact cells; wall cells square, rectangular or hexagonal, arranged in longitudinal rows, average size of cells 35 x 24 microns; a transparent outer layer covering the cuticle present in well preserved specimens.

Figured specimens: Figures 9, 10: the holotype; locality: Standard; level: "White Sandstone", 2.5 m below contact with the Battle Member; slide No. PB/P1/4. Figure 11: locality: Standard; level: "White Sandstone", 4.5 m below contact with the Battle Member; slide No. PB/Q3/1.

Remarks: This subspecies is remarkably smaller than *S. ellipticus* Miner 1935 although no morphological difference exists between the two forms. It can easily be seen in Figure 19 that none of the 32 specimens measured herein falls in the size range of *S. ellipticus* Miner 1935.

Spermatites saskatchewanicus sp. nov.

Plate XI, figures 1, 2

Description: Shape elliptical to oblong with convex sides; length 684 to 836 microns, average 747 microns; width 355 to 456 microns, average 406 microns; L/W ratio 1.80 to 2.14, average 1.84; maximum width at mid-part or slightly above it; base founded with a short stalk or a remnant of stalk; apex tapering to a rounded end with cells smaller than on the rest of the body, at times masked by dark dense material; cells small and of irregular shapes without a particular arrangement, average diameter of cells 20 microns; a transparent outer layer covering the cuticle present in all the examined specimens.

Figured specimens: Figure 1: the holotype; locality: Eastend; level: Whitemud Formation; slide No. PB/H25/3. Figure 2: locality, level, and slide: same as holotype.

Remarks: *S. saskatchewanicus* is easily differentiated by its small size and the irregular arrangement of the cells. It is fairly abundant at the above mentioned locality but it was not found elsewhere.

Spermatites pinguis sp. nov.

Plate XII, figure 3

Description: Shape elliptical; average length 847 microns; average width 588 microns; average L/W ratio 1.44 (4 individuals measured); maximum width near base; base rounded with remnant of stalk showing; apex sharply pointed with cells masked at times by dark dense material; cells small and of irregular shapes, without a particular arrangement, average diameter of cells 60 microns; transparent outer layer covering the cuticle present in all the examined specimens.

Figured specimen: Figure 3: the holotype; locality: Eastend; level: Whitemud Formation; slide No. PB/H30/10.

Remarks: *S. pinguis* is easily recognizable by its size, shape and by the irregular arrangement of the cells. It is rare, only 4 specimens were found and only in the above mentioned locality.

Spermatites robustus sp. nov.

Plate XII, figure 4

Description: Shape elliptical; length 1140 to 1290 microns, average 1222 microns; width 730 to 835 microns, average 778 microns; L/W ratio 1.48 to 1.64, average 1.57; maximum width at mid-part; base generally rounded, slightly flattened showing a remnant of stalk; apex terminated in a blunt point protruding from the rounded outline; wall cells hexagonal slightly elongated normally to the long axis of body and arranged in imperfect longitudinal rows, average size of cells 100 x 75 microns; a transparent outer layer covering the cuticle present in all specimens.

Figured specimen: Figure 4: the holotype; locality: Horseshoe Canyon; level: "White Sandstone", 5.5 m below contact with the Battle Member; slide PB/A11/11.

Remarks: S. robustus differs from other species in its large size, low length-to-width ratio and its hexagonal cellular structure that seems to be somewhat transitional towards a Costatheca-type.

Spermatites nanus Miner 1935

Plate XII, figure 7

Description: Shape elliptical with straight sides; average length 640 microns, average width 283 microns; average L/W ratio 2.26; maximum width at middle part; base concave with funnel-shaped stalk 50 microns long and 60 microns wide at base; apex rounded and covered by dark carbonaceous matter; wall cells square, rectangular

pentagonal and hexagonal arranged in longitudinal rows; average size of cells 30 x 25 microns; remnants of double wall still visible in places.

Figured specimen: Figure 7: locality: Standard; level: "White Sandstone", 4 m below contact with the Battle Member; slide No. PB/Q4/2.

Remarks: Very few specimens belonging to this species were found during the present investigation. They conform with Miner's description except for having straighter sides than the specimens from Greenland. They fall in the size range of Miner's specimens: length 589 to 680 microns, width 266 to 315 microns, average 647 x 290 microns.

Affinities of the Genus Spermatites

The natural affinities of the fossil form-genus *Spermatites* were investigated in the present work. After Miner's (1935) suggestion that these fossils could "represent primitive orthotropous or slightly amphytropous seeds", a number of monocotyledonous seeds were examined. Among these the seeds of *Juncus* seemed to provide the best fit for *Spermatites*. The fossil material was compared with descriptions and illustrations given by Arber (1925), Fernald (1950), Martin and Barkley (1961) and Katz *et al*. (1965). Seeds of a few modern species of *Juncus* were treated, mounted and examined. Seed cuticles belonging to the modern species *J. alpinus*, *J. bufonius*, *J. balticus*, and treated in order to eliminate the cytoplasm (see page 122) are shown for comparison in Plates XI and XII. The similarity of all forms of *Spermatites*, with the exception perhaps of *S. robustus*, with *Juncus*

seeds is reasonably convincing. Shape, size and wall structure provide enough evidence to assign these fossils to late Mesozoic forms of *Juncus*, if not to living species. The form-generic name *Spermatites* is, however, retained for these fossils at least until further evidence, such as other plant remains, can be found in association with the seed cuticles.

Genus COSTATHECA Hall 1967

Chrysotheca Miner 1935, p. 590, pl. 18, figs. 1-10.

non *Chrysotheka* Doflein 1923, p. 333-334, pl. 22, figs. 44, 45.

non *Chrysotheca* Scherffel 1927, p. 335-337, pl. 15, figs. 7-11.

Type species *Costatheca diskoensis* (Miner) Hall 1967

Chrysotheca diskoensis Miner 1935, p. 590, fig. 5, lectotype

Diagnosis: Plant body small, ovate, elongate, lanceolate, straight or curved, with few to several plications or ribs, sessile or apparently short stalked; well preserved specimens showing a wall composed of two or three layers; cells of the outer layer hexagonal or rectangular and elongated perpendicular to the long axis of the body.

Remarks: Microfossils belonging to this genus were originally described under the genus *Chrysotheca* by Miner (1935). Hall (1967) proposed that the name be changed as it had previously been used, in the two slightly different orthographic versions of *Chrysotheka* and *Chrysotheca*, for members of the chrysophicean algae.

The generic diagnosis of *Costatheca* is here restricted to specimens that, conforming in all other respects with Miner's original diagnosis, show a cellular structure of the type described above. This

differential diagnosis is in fact necessary in order to discriminate between Costatheca (cells elongated perpendicular to the body), Spermatites Miner 1935 (cells more or less equilateral and generally smaller), and Carpotheca (cells elongated parallel to the body).

Since several species of Costatheca already in the literature were described upon examination of loose specimens under stereoscopic microscope, the comparison of the specimens described herein with known species, and the discrimination at the specific level had to be based mainly on size parameters. Vangerow (1954) had already shown the usefulness of plots of length and width as a discriminatory criterion at the specific level. The plot of length versus length-to-width (abbreviated L/W in the text) ratio was found to be a useful parameter for the discrimination of species of Costatheca (Fig. 20). The plot of such data defines ideal fields for already known species (solid-line rectangles in Fig. 20). Measurements of well-preserved specimens of Costatheca from southern Alberta and southwestern Saskatchewan were subsequently plotted in the diagram and compared with Vangerow's specimens. The fields of three new species are defined by dashed-line rectangles in Figure 20.

The comparison with species described by other authors, for which the set of measurements was incomplete or insufficient, was mainly based on general size and shape parameters and on ornamentation.

Recorded Distribution of the Genus Costatheca

-- Disko Island, Greenland, from Upper Cretaceous coals (Miner, 1935): C. diskoensis.

-- South Limburg, Netherlands, from sediments of Aachenian age (Dijkstra, 1949): C. tenuis, C. quadruplicata, C. striata, C. dentata.

-- Plymouth County, Iowa, from coals of the Dakota Formation of Cenomanian age (Schemel, 1950 and Hall, 1963): C. dakotaensis, C. levis, C. diskoensis.

-- Northeastern Utah and southwestern Wyoming, from sediments of the Wanship Formation of Danian-u. Maestrichtian age (Peterson et al., 1953): figs. 1, 2, 4, 5, 6, 7, 8 of Plate XIV, p. 144 show various types of "Chrysotheca", but the authors do not identify them by the generic name and refer to them as "seeds".

-- Aachen, Germany, from sediments of the Basiston and Aachener Sand of Late Cretaceous age (Vangerow, 1954): C. striata, C. lata, C. exilis, C. ovata, C. levis.

Costatheca striata (Dijkstra) Hall 1967

Plate XIII, figures 1-5

Description: Shape oblong, ovate, lanceolate or narrow elliptical with pointed ends; sides both convex or one convex and one straight to slightly concave; length 812 to 1636 microns, average 1147 microns; width 381 to 640 microns, average 486 microns; L/W ratio 1.71 to 2.94, average 2.42; maximum width at approximately mid-part; 5 to 10 longitudinal plications; opening fringed or laciniate or closed by

the same dense dark material present at the rounded or slightly pointed apical end; three-layered wall (fig. 5); outer layer 15 to 20 microns thick, composed of a golden-brown fairly resistant organic material and showing a cellular structure of hexagonal to rectangular units up to 150 microns long and 15 to 25 microns wide; middle layer of lighter color, less resistant material, 10 to 12 microns thick; inner layer of same composition as the outer, showing only faint traces of the cellular structure (fig. 2).

Figured specimens: Figure 1: locality: Nevis Bridge; level: "White Sandstone", 7 m below contact with the Battle Member; slide No. PB/U7/1. Figure 2: locality and level: same as above; slide No. PB/U7/7. Figures 3, 4: locality: Standard; level: "White Sandstone", 4 m below contact with the Battle Member; slide No. PB/Q4/6. Figure 5: locality: Red Deer River Valley, west of Scollard; level: "White Sandstone", 2 m below contact with the Battle Member; slide No. PB/O10/20.

Remarks: C. striata displays a certain variety of shapes and sizes. Following Vangerow (1954), the L/W ratio has been considered a diagnostic character for the species. The diagram of Figure 20 shows that the thirty-nine individuals measured fall very well in the field of Vangerow's measurements with the exception of three specimens displaying larger size but the same L/W ratio.

Costatheca lata (Vangerow) Hall 1967

Plate XIV, figures 6, 7

Description: Shape oval, one side convex the other convex, straight or S-shaped; average length 728 microns, average width 434 microns; average L/W ratio 1.69; maximum width circa at middle part; 8 longitudinal plications; opening fringed or laciniate; apex rounded, wall cells of typical Costatheca-type but not too distinct.

Figured specimens: Figure 6: locality: Nevis Bridge; level: "White Sandstone", 7 m below contact with the Battle Member; slide No. PB/U7/3. Figure 7: locality: Horseshoe Canyon, 4.8 m below contact with the Battle Member; slide No. PB/A14/16.

Remarks: Only four specimens attribuatable to this species were found. They fit the original description and fall in the size ranges given by Vangerow: length 630 to 980 microns, average 714 microns; width 378 to 560 microns, average 490 microns; L/W ratio 1.3 to 2.1, average 1.76 (20 individuals measured).

Costatheca exilis (Vangerow) Hall 1967

Plate XIV, figure 2

Description: Rod-shaped with straight sides; average length 1136 microns; average width 292 microns; average L/W ratio 3.89; 5 to 6 longitudinal plications; opening indistinct; apical end rounded with a dense mass of dark carbonaceous material masking the cells; wall cells not clear enough to be measured.

Figured specimen: Figure 2: locality: Red Deer River Valley, near Scollard; level: "White Sandstone", 7.5 m below contact with the Battle Member; slide No. PB/M4/1.

Remarks: Vangerow's size ranges for _C. exilis_ are: length 980 to 1400 microns; width 280 to 350 microns; L/W ratio 3.3 to 4.0. Of the five individuals attributable to this species that were found in the material described here, three have higher L/W ratios than Vangerow's specimens, however, they conform to the original definition in every other respect.

Costatheca minerii sp. nov.

Plate XIII, figures 6-8

Description: Shape curved, with one side convex and the other straight or concave; length 1808 to 2288 microns, average 2053 microns; width 504 to 787 microns, average 634 microns; L/W ratio 2.59 to 407, average 3.24; maximum width from middle part to near the apical end; 5 to 10 longitudinal plications; opening distinct or blocked by carbonaceous matter; wall cells hexagonal or rectangular up to 200 microns long and 10 to 28 microns wide arranged in longitudinal rows.

Figured specimens: Figures 6, 7: the _holotype_; locality: Standard; level: "White Sandstone", 2.5 m below contact with the Battle Member; slide No. PB/P1/1. Figure 8: locality: Nevis Bridge; level: "White Sandstone", 7 m below contact with the Battle Member; Slide No. PB/U7/6.

Remarks: C. minerii can be recognized by its large size, its high L/W ratio (Fig. 20) and its shape. The specific epithet is given in honour of E.L. Miner.

Costatheca inflata sp. nov.

Plate XIV, figure 1

Description: Plant body small, broadly lanceolate; average length 1382 microns; average width 738 microns; average L/W ratio 1.76; maximum width from middle part to near the apical end; 6 to 8 longitudinal plications; opening laciniate; apex sharply pointed; wall cells hexagonal or rectangular up to 150 microns long and 10 to 25 microns wide arranged in longitudinal rows.

Figured specimen: Figure 1: the holotype; locality: Horseshoe Canyon; level: "White Sandstone", 5 m below contact with the Battle Member; slide No. PB/A11/15.

Remarks: C. inflata was established on only four specimens. Its main characteristics are the large size and low L/W ratio and the broad lanceolate shape. The field of measurements tentatively traced in the diagram of Figure 20 is obviously a minimal one.

Costatheca pusilla sp. nov.

Plate XIV, figures 3-5

Description: Shape narrow elliptical with straight sides or curved with one side convex and the other straight to slightly concave; length 502 to 927 microns, average 701 microns; width 152 to 285 microns, average 222 microns; L/W ratio 224 to 452, average 316;

maximum width at middle part; 5 to 10 longitudinal plications 10 to 20 microns wide; opening end bearing a conical stalk up to 125 microns long and 160 microns wide at the base; stalk composed of very small, densely packed cells, often completely masked by carbonaceous matter; apical end rounded or slightly pointed, with the same cell structure as the stalk; wall thin; wall cells small rectangular 30 microns long, 5 microns wide, often indistinct.

Figured specimens: Figure 3: the holotype; locality: Red Deer River Valley, near Scollard; level: "White Sandstone", 7.5 m below contact with the Battle Member; slide No. PB/M4/7. Figure 4: locality and level: same as holotype; slide No. PB/M4-5/20. Figure 5: locality and level: same as holotype; slide No. PB/M4/3.

Remarks: *C. pusilla* displays a variety of shapes, but it is characterized by its relatively small size, thin wall and a very small variety of the *Chrysotheca*-type cellular structure. Its field of measurements (Fig. 20) overlaps with the field of *C. striata* but the two species are otherwise very easily distinguished.

Affinities of the Genus Costatheca

The natural affinities of the fossil genus *Costatheca* are uncertain. Miner (1935) described it under the heading BRYOPHYTA, basing his attribution upon the comparison that Arnold (1932) had made of similar objects with bryophytic antheridia. *Costatheca* was therefore assigned to the *Jungermanniales*. Such affinity is not completely convincing according to Vangerow (1954) who preferred to consider

Costatheca as a spore-case (Sporenkapsel). He admitted, however, that the question is still open. Arnold (written communication) discounts any comparison with the Jungermanniales and believes that Costatheca can be without any doubt considered a seed cuticle. Hall (written communication) also rejects the idea of a bryophyte perianth, at least for C. dakotaensis. A number of texts were consulted in the hope of finding a possible affinity with Quaternary and present day seeds. Some of the illustrations given by Katz et al. (1965) of Quaternary seeds of the family Compositae have a remarkable resemblance to Costatheca. Palynological slides of Costatheca-bearing sediments were prepared and analyzed. Since no pollen attributable to Compositae was found, this possibility was discarded. The question of the natural affinity of this fossil cuticle is therefore still open, although there is a strong likelihood of it being a seed cuticle.

Genus CARPOTHECA gen. nov.

Type species Carpotheca elegans sp. nov.

Diagnosis: Plant body elongate, L/W ratio higher than 2; straight or curved, spindle shaped, elliptical or lanceolate; with or without stalk; wall smooth, finely cellular, longitudinally striated or composed of large rectangular to irregular cells elongated parallel to long axis of body.

Remarks: The main discriminatory character for the genus Carpotheca is the cell structure that distinguishes it from Spermatites and Costatheca. It is furthermore distinguishable from the first by its very elongated shape and from the latter by the absence of regular plications or ribs.

Carpotheca elegans sp. nov.

Plate XIV, figures 8, 9

Description: Shape narrow elliptical to lanceolate; length 1,328 to 2,398 microns, average 1,799; width 274 to 529 microns, average 372 microns; L/W ratio 2.63 to 6.62, average 4.83 (25 specimens measured); maximum width from middle part to opening end; irregular longitudinal folds may be present; opening end gently rounded or showing a remnant of stalk; apex usually pointed with cell structure masked by dark carbonaceous matter; wall thin; wall cells rectangular or of irregular shape, straight or curved, elongate parallel to long axis of body; cells size up to 110 x 25 microns.

Figured specimen: Figures 8, 9: the holotype; locality: Standard; level: "White Sandstone", 4 m below contact with the Battle Member; slide No. PB/Q4/10.

Remarks: C. elegans displays a wide range of sizes, but it is easily recognizable by its shape and wall structure.

Carpotheca parva sp. nov.

Plate XIV, figure 12

Description: Shape narrow elliptical with both sides convex or flattened at middle part; length 806 to 1307 microns, average 1009 microns; width 275 to 502 microns, average 378 microns; L/W ratio 2.27 to 3.23, average 2.67 (4 specimens measured); opening end rounded with a short remnant of stalk; apex rounded or slightly flattened with dark carbonaceous matter covering the tip; wall thin, covered by fine longitudinal striations; wall cells indistinct.

Figured specimen: Figure 12: the holotype; locality: Eastend; level: Whitemud Formation; slide No. PB/H30/9.

Remarks: *C. parva* differs from *C. elegans* in having smaller size and L/W ratio. Moreover the apical end is always rounded or flattened.

Carpotheca coronata sp. nov.

Plate XIV, figures 10, 11

Description: Shape elliptical truncated; length 760 to 942 microns, average 851 microns; width 228 to 380 microns, average 293 microns; L/W ratio 2.36 to 3.43, average 2.90 (5 specimens measured); maximum width at middle part; opening end flat to concave with a pointed stalk 75 microns long and 40 microns wide at base, surrounded by a thin calix-like rim extending upwards and slightly outwards 30 to 40 microns high; apex tapering to a dark, dense carbonaceous tip; wall thin; wall cells small, rectangular, elongated perpendicular to long axis of the body, 40 microns long and 9 microns wide, but indistinct in most individuals.

Figured specimens: Figure 10: the holotype; locality: Eastend; level: Whitemud Formation; slide No. PB/H30/9. Figure 11: locality and level: same as holotype; slide No. PB/H30/10.

Remarks: *C. coronata* is easily recognizable by the presence of the rim at the opening end.

Carpotheca falcata sp. nov.

Plate XIV, figures 13, 14

Description: Shape falcate with one side concave and the other convex; length 958 to 1581 microns, average 1237 microns; width 220 to 292 microns, average 267 microns; L/W ratio 3.83 to 5.41, average 4.63 (8 specimens measured); width constant for most of the length of the body; opening end rounded or slightly flattened; apex rounded with dark carbonaceous matter at the extremity; wall thin, wall cells rectangular, elongated parallel to the long axis of the body, arranged in longitudinal rows; average size of cells 42 x 19 microns.

Figured specimens: Figure 13: the holotype; locality: Eastend; level: Whitemud Formation; slide No. PB/H30/9. Figure 14: locality, level and slide: same as holotype.

Remarks: *C. falcata* is easily recognizable by its arcuate shape.

Affinities of the Genus Carpotheca

Since the form-genus *Carpotheca* allows for a great amount of variations at the specific level, the individual species described under this genus will have to be dealt with separately with regard to their possible biological affinities.

Comparison of the fossil species described herein with seeds illustrated in various texts reveals a strong resemblance of the species *C. coronata* with seeds of the monocotyledon *Typha* illus-

trated by Katz et al. (1965, p. 267) and by Godwin (1956, pl. XX, fig. c). For the other three species, however, no positive affinity can be suggested, although it is quite likely that they are seed cuticles.

REFERENCES

Allan, J.A. and J.O.G. Sanderson (1945): Geology of the Red Deer and Rosebud Sheets, Alberta; Res. Coun. Alberta Rept. 13, 109 pages.

Arber, A. (1925): Monocotyledons, a morphological study; Cambridge University Press, London, 258 pages.

Arnold, C.A. (1932): Microfossils from Greenland coal; Papers of the Michigan Acad. Sci. Arts and Letters, Vol. 15, p. 51-61.

____________ (1948): Some cutinized seed membranes from the coal bearing rocks of Michigan; Torrey Bot. Club Bull., Vol. 75, p. 131-146.

Bagnold, R.A. (1966): An approach to the sediment transport problem from general physics; U.S. Geol. Surv. Prof. Paper 422, p. 11-137.

Bell, W.A. (1949): Uppermost Crectaceous and Paleocene floras of western Alberta; Geol. Surv. Can. Bull. 13, 231 pages.

Berry, E.W. (1935): A preliminary contribution to the floras of the Whitemud and Ravenscrag Formations; Geol. Surv. Can. Mem. 182, 107 pages.

Bihl, G. (1968): Palynological correlation of Late Cretaceous beds, Shearness, Alberta; unpublished M.Sc. thesis, Dept. Geology, Univ. of Alberta, 72 pages.

Binda, P.L. (1968): New species of Spermatites from the Upper Cretaceous of southern Alberta; Rev. Micropaleont., Vol. 11, p. 137-142.

___________ (1969): Provenance of the Upper Cretaceous Kneehills Tuff, southern Alberta; Can. Jour. Earth Sci., Vol. 6, p. 510-513.

Binda, P.L. and S.K. Srivastava (1968): Silicified megaspores from Upper Cretaceous beds of southern Alberta, Canada; Micropaleont., Vol. 14, p. 105-113.

Blatt, H. (1967): Original characteristics of clastic quartz grains; Jour. Sed. Petrology, Vol. 37, p. 401-424.

Blatt, H. and J.M. Christie (1963): Undulatory extinction in quartz of igneous and metamorphic rocks and its significance in provenance studies of sedimentary rocks; Jour. Sed. Petrology, Vol. 33, p. 559-579.

Boggs, S. Jr. (1967): A numerical method for sandstone classification; Jour. Sed. Petrology, Vol. 37, p. 548-555.

Brown, C.A. (1960): Palynological Techniques; published by the author, Baton Rouge, La., 188 pages.

Bull, W.B. (1962): Relation of textural (CM) patterns to depositional environments of alluvial-fan deposits; Jour. Sed. Petrology, Vol. 32, p. 211-216.

Byers, P.N. (1969): Mineralogy and origin of the upper Eastend and Whitemud Formation of south-central and southwestern Saskatchewan and southeastern Alberta; Can. Jour. Earth Sci., Vol. 6, p. 317-334.

Byrne, P.J.S. (1951): Sediments associated with the Kneehills Tuff in the Edmonton area; unpublished M.Sc. thesis, Dept. Geology, Univ. of Alberta, 67 pages.

Campbell, J.D. (1962): Boundaries of the Edmonton Formation in the central Alberta Plains; Jour. Alberta Soc. Petrol. Geol., Vol. 10, p. 308-319.

Carozzi, A.V. (1956): Problèmes de sédimentation et de corrélation dans le groupe de Platteville (Ordovicien moyen) de l'Iowa, Illinois et Indiana; U.S.A; Archieves de Sciences, Vol. 9, p. 283-302.

_____________ (1958): Micro-mechanisms of sedimentation in the epicontinental environment; Jour. Sed. Petrology, Vol. 16, p. 133-150.

_____________ (1960): Microscopic sedimentary petrography; John Wiley and Sons, New York, 485 pages.

Carrigy, M.A. and G.B. Mellon (1964): Authigenic clay mineral cements in Cretaceous and Tertiary sandstones of Alberta; Jour. Sed. Petrology, Vol. 34, p. 461-472.

Chi, B.I. (1966): A petrologic comparison of the Frenchman and Upper Edmonton Formations; unpublished M.Sc. theseis, Dept. Geology, Univ. of Alberta, 124 pages.

Clemens, W.A. (1960): Stratigraphy of the type Lance Formation; Internat. Geol. Congr., Rept. 21st Norden, Pt. V, p. 7-13.

Clemens, W.A. and L.S. Russell (1965): Mammalian fossils from the Upper Edmonton Formation; <u>in</u> Vertebrate Paleontology in Alberta, Rept. Conf. Univ. Alberta (Aug. 29-Sept. 3, 1963), Univ. Alberta, Edmonton, p. 32-40.

Cookson, I.C. and M.E. Dettmann (1958): Cretaceous "megaspores" and a closely associated microspore from the Australian region; Micropaleont., Vol. 4, p. 39-49.

Craig, H. (1953): The geochemistry of the stable carbon isotopes; Geochim. Cosmochim. Acta, Vol. 3, p. 53-92.

Crockford, M.B.B. and W.H.A. Clow (1965): Upper Cretaceous formations of the Cypress Hills-Milk River area, southeastern Alberta and southwestern Saskatchewan; Alberta Soc. Petroleum Geol., 15th Ann. Field Conf. Guidebook, Pt. 1, p. 184-197.

Cuthbert, F.L. (1944): Clay minerals in Lake Erie sediments; Am. Mineral., Vol. 29, p. 378-388.

Davis, N.B. (1918): Report on the clay resources of southern Saskatchewan; Can. Mines Branch Rept. 468.

Deák, M.H. and A. Combaz (1967): "Microfossiles organiques" du Wealdien et du Cénomanien dans un sondage de Charente-Maritime; Rev. Micropaleont., Vol. 10, p. 69-96.

Dijkstra, S.J. (1949): Megaspores and some other fossils from the Aachenian (Senonian) in south Limburg, Netherlands; Meded. Geol. Stichting, Niewe Serie, Vol. 3, p. 19-32.

______________ (1951): Wealden megaspores and their stratigraphic value; Meded. Geol. Stichting, Niewe Serie, Vol. 5, p. 7-21.

______________ (1959): On megaspores, charophyta fruits and some other small fossils from the Cretaceous; Paleobot., Vol. 8, p. 8-18.

______________ (1961): Some Paleocene megaspores and other small fossils; Meded. Geol. Stichting, Niewe Serie, Vol. 13, p. 5-11.

Dodge, C.F. (1965): Genesis of an Upper Cretaceous offshore bar near Arlington, Texas; Jour. Sed. Petrology, Vol. 35, p. 22-25.

Doeglas, D.J. (1946): Interpretation of the results of mechanical analyses. Jour. Sed. Petrology, Vol. 16, p. 19-40.

_____________ (1950): De interpretatie van de korrelgrootte analysew, I-V; Verh. kon. Ned. Geol.-mijnbouwk, Genootschap, Deel XV, p. 247-328.

_____________ (1968): Grain-size indices, classification and environment; Sediment., Vol. 10, p. 83-100.

Dorofeev, P.I. (1959): New species of Azolla Lamark in Tertiary flora of U.S.S.R.; Botanicheskij Zhurnal SSSR, Vol. 44, p. 1756-1763 (translated by A. Vagvolgyi and L. Hills).

Dott, R.H., Jr. (1964): Wacke, graywacke and matrix--what approach to immature sandstone clasification?; Jour. Sed. Petrology, Vol. 34, p. 625-632.

Doty, R.W. and J.F. Hubert (1962): Petrology and paleogeography of the Warrensburg channel sandstone, western Missouri; Sediment., Vol. 1, p. 7-39.

Elliott, R.H.J. (1960): Subsurface correlation of the Edmonton Formation; Jour. Alberta Soc. Petroleum Geol., Vol. 8, p. 324-338.

Esau, K. (1965): Plant Anatomy, 2nd edition; John Wiley and Sons, New York, 767 pages.

Fernald, M.L. (1950): Grey's manual of botany, 8th edition; American Book Co., New York, 1632 pages.

Folinsbee, R.E., H. Baadsgaard, and J. Lipson (1961): Potassium-argon dates of Upper Cretaceous ash falls, Alberta, Canada; Ann. New York Acad. Sci., Vol. 91, p. 352-359.

Folk, R.L. (1954): The distinction between grain size and mineral composition in sedimentary rock nomenclature; Jour. Geology, Vol. 62, p. 334-359.

__________ (1961): Petrology of sedimentary rocks; Hemphills, Austin, Texas, 154 pages.

__________ (1966): A review of grain-size parameters; Sediment., Vol. 7, p. 73-93.

Folk, R.L. and W.C. Ward (1957): Brazos River bar, a study in the significance of grain-size parameters; Jour. Sed. Petrology, Vol. 27, p. 3-27.

Fraser, F.J., F.H. McLearn, L.S. Russel, P.S. Warren, and R.T.D. Wickenden (1935): Geology of southern Saskatchewan; Geol. Surv. Can. Mem. 176, 137 pages.

Friedman, G.M. (1961): Distinction between dune, beach and river sands from their textural characteristics; Jour. Sed. Petrology, Vol. 31, p. 514-529.

______________ (1967): Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands; Jour. Sed. Petrology, Vol. 37, p. 327-354.

Furnival, G.M. (1946): Cypress Lake map area, Saskatchewan; Geol. Surv. Can. Mem. 242, 161 pages.

Gibbs, R.J. (1965): Error due to segregation in quantitative clay mineral X-ray diffraction mounting techniques; Am. Mineral., Vol. 50, p. 741-751.

__________ (1968): Clay mineral mounting techniques for X-ray diffraction analysis: a discussion; Jour. Sed. Petrology, Vol. 38, p. 242-244.

Gilbert, C.M. (1954): Sedimentary rocks <u>in</u> Williams, H, F.J. Turner, and C.M. Gilbert, Petrography; Freeman & Co., San Francisco, p. 251-384.

Godwin, H. (1956): The History of British Flora. The University Press, Cambridge, 384 pages.

Goldstein, A. Jr. (1959): Cherts and novaculites of Ouachita facies; <u>in</u> Silica in Sediments; Soc. Econ. Paleontologists and Mineralogists, Special Publication 7, p. 135-149.

Grim, R.E. (1968): Clay Mineralogy, 2nd edition; McGraw-Hill, New York, 596 pages.

Grim, R.E., R.S. Dietz, and W.F. Bradley (1949): Clay mineral composition of some sediments from the Pacific Ocean off the California Coast and the Gulf of California; Bull. Geol. Soc. Am., Vol. 60, p. 1785-1808.

Hall, J.W. (1963): Megaspores and other fossils in the Dakota Formation (Cenomanian) of Iowa (U.S.A.); Pollen et Spores, Vol. 5, p. 425-443.

__________ (1967): Invalidity of the name <u>Chrysotheca</u> Miner for microfossils; Jour. Paleont., Vol. 41, p. 1298-1299.

Hedlund, R.W. (1966): Palynology of the Red Branch Member of the Woodbine Formation (Cenomanian), Bryan County, Oklahoma; Oklahoma Geol. Surv. Bull. 112, 69 pages.

Heinrich, E.W. (1956): Microscopic petrography; McGraw-Hill Co., New York, 296 pages.

Hills, L.V. and N. Weiner (1965): <u>Azolla geneseana</u>, n. sp. and revision of <u>Azolla primaeva</u>; Micropaleont., Vol. 11, p. 255-261.

Hodgson, W.A. (1968): The diagenesis of spherulitic carbonate concretions and other rocks from Mangakahia Group sediments, Kaipara Harbour, New Zealand; Jour. Sed. Petrology, Vol. 38, p. 1254-1263.

Hughes, N.F. (1955): Wealden plant microfossils; Geol. Magazine, Vol. 92, p. 201-217.

___________ (1961): Further interpretation of Eucommidites Erdtman 1948; Paleont., Vol. 4, p. 292-299.

Imbrie, J. and E.O. Purdy (1962): Classification of modern Bahamian carbonate sediments, in Haw, W.E., ed., Classification of carbonates rocks; a symposium; Am. Assoc. Petrol. Geol. Mem. 1, p. 253-272.

Imbrie, J. and Tj.R. Van Andel (1964): Vector analysis of heavy mineral data; Bull. Geol. Soc. Am., Vol. 75, p. 1131-1156.

Inman, D.L. (1952): Measures for describing the size distribution of sediments; Jour. Sed. Petrology, Vol. 22, p. 125-145.

Irish, E.J.W. and C.J. Havard (1968): The Whitemud and Battle Formations ("Kneehills Tuff zone"); a stratigraphic marker; Geol. Surv. Can. Paper 67-63, 51 pages.

Jeletzky, J.A. (1960): Youngest marine rocks in western interior of North America and the age of Triceratops beds, with remarks on comparable dinosaur bearing beds outside North America; Internat. Geol. Congr., Rept. 21st Norden, Pt. V, p. 25-40.

Johns, W.D., R.E. Grim and W.F. Bradley (1954): Quantitative estimation of clay minerals by diffraction methods; Jour. Sed. Petrology, Vol. 24, p. 242-251.

Kaisin, F. Jr. (1943): Concrétions de siderose à texture granuleuse des couches de houille; Bull. Soc. belge géol. pal. hydr., Vol. 51, p. 32-49.

Katz, N. Ja., S.V. Katz and M.G. Kipiani (1965): Atlas and keys of fruits and seeds occurring in the Quaternary deposits of the U.S.S.R.; Acad. Sci. U.S.S.R., Commission for Investigations of the Quaternary Period, Nauka, Moscow, 366 pages.

Keith, M.L. and J.N. Weber (1964): Carbon and oxygen isotopic composition of selected limestones and fossils; Geochim. Cosmochim. Acta, Vol. 28, p. 1787-1816.

Keller, W.D.(1962): Clay minerals in the Morrison Formation of the Colorado Plateau; U.S. Geol. Surv. Bull. 1150, 90 pages.

King, L.C. (1967): Morphology of the Earth; Oliver and Boyd Ltd., Edminburgh, 726 pages.

Klein, G. DeVries (1963): Analysis and review of sandstone classifications in the North American geological literature; Bull. Geol. Soc. Amer., Vol. 74, p. 555-576.

Klovan, J.E. (1966): The use of factor analysis in determining depositional environments from grain-size distributions; Jour. Sed. Petrology, Vol. 36, p. 115-125.

____________ (1968): Q-Mode factor analysis program in Fortran IV for small computers, in Merriam, D.E., ed., Computer programs for multivariate analysis in geology; Kansas Geol. Surv., Univ. Kansas, Computer Contribution 20, p. 39-51.

Kondinskaya, L.I. (1966): Fossil spores of water ferns in Upper Cretaceous and Paleogene deposits of west Siberian lowland, in Palynology of Siberia; Acad. Sci. SSSR, Nauk, p. 116-122 (in Russian with summary in English).

Krumbein, W.C. (1934): Size frequency distribution of sediments; Jour. Sed. Petrology, Vol. 4, p. 65-77.

Krumbein, W.C. and E.J. Aberdeen (1937): The sediments of Barataria Bay (La.); Jour. Sed. Petrology, Vol. 7, p. 3-17.

Krumbein, W.C. and R.M. Garrels (1952): Origin and classification of chemical sediments in terms of pH and oxidation-reduction potentials; Jour. Geology, Vol. 60, p. 1-30.

Krumbein, W.C. and F.J. Pettijohn (1938): Manual of sedimentary petrography; Appleton-Century-Crofts, New York, 549 pages.

Krumbein, W.C. and L.L. Sloss (1963): Stratigraphy and sedimentation, 2nd ed.; Freeman & Co., San Francisco, 497 pages.

Krynine, P.D. (1940): Petrology and genesis of the Third Bradford Sand. Penn. State College, Min. Ind. Expt. Station Bull. 29, 134 pages.

____________ (1948): The megascopic study and field classification of sedimentary rocks; Jour. Geol., Vol. 56, p. 130-165.

Kupsch, W.O. (1956): Geology of eastern Cypress Hills; Sask. Dept. Mineral Res. Rept. 20, 30 pages.

Langston, W. Jr. (1965): Pre-Cenozoic vertebrate paleontology in Alberta: its past and future; in Vertebrate Paleontology in Alberta, Rept. Conf. Univ. Alberta (Aug. 29-Sept. 3, 1963), Univ. Alberta, Edmonton, p. 9-31.

Lerbekmo, J.F. (1957): Authigenic montmorillonoid cement in andesitic sandstones of central California; Jour. Sed. Petrology, Vol. 27, p. 298-305.

McBride, E.F. (1963): A classification of common sandstones; Jour. Sed. Petrology, Vol. 33, p. 664-669.

McCrea, J.M. (1950): On the isotopic chemistry of carbonates and a paleotemperature scale; Jour. Chem. Phys., Vol. 18, p. 849-857.

Mahabalé, T.S. (1963): Evolutionary tendencies in the genus Azolla; Memoirs Indian Botanical Soc., Vol. 4, p. 51-54.

Martin, A.C. and W.D. Barkley (1961): Seed identification Manual; Univ. of California Press, Berkeley, California, 221 pages.

Mason, C.C. and R.L. Folk (1958): Differentiation of beach, dune, and eolian flat environments by size analysis, Mustang Island, Texas; Jour. Sed. Petrology, Vol. 28, p. 211-226.

Mellon, G.B. (1960): Authigenic processes in the Lower Cretaceous Blairmore Group, Alberta; Geol. Soc. Amer., Prog. Ann. Meeting (Abstr.).

Millot, G.(1964): Géologie des argiles; Masson et C^ie^, Paris, 499 pages.

Minakami, T. (1942): On the distribution of volcanic ejecta; the distribution of Mt. Asama pumice in 1873, part 2; Bull. Earthquake Res. Inst., Tokyo Univ., Vol. 20, p. 93-105.

Miner, E.L. (1932): Megaspores ascribed to Selaginella from the Upper Cretaceous coals of western Greenland; Jour. Wash. Acad. Sci., Vol. 22, p. 497-506.

___________ (1935): Paleobotanical examination of Cretaceous and Tertiary coals; Amer. Midl. Nat., Vol. 16, p. 585-626.

Moiola, R.J. and D. Weiser (1968): Textural parameters: an evaluation; Jour. Sed. Petrology, Vol. 38, p. 45-53.

Murata, K.J., I.I. Friedman and B.M. Madsen (1967): Carbon-13-rich diagenetic carbonate in Miocene formations of California and Oregon; Science, Vol. 156, p. 1484-1486.

Murray, N. (1939): The microflora of the Upper and Lower Estuarine Series of the East Midlands; Geol. Magazine, Vol. 76, p. 478-488.

Nelson, B.W. (1960): Clay mineralogy of the bottom sediments, Rappahannock River, Virginia; Clays and Clay Minerals (7th Nat. Conf., 1958), p. 135-148.

Norton, N.J. and J.W. Hall (1967): Guide sporomorphae in the Upper Cretaceous-Lower Tertiary of eastern Montana; Rev. Palaeobot. Palynol., Vol. 2, p. 99-110.

Oinuma, K. and K. Kobayashi (1960): Problems of rapid clay mineralogical analysis of sedimentary rocks; Clay Sci., Vol. 1, p. 8-15.

Ower, J.R. (1960): The Edmonton Formation; Jour. Alberta Soc. Petroleum Geol., Vol. 8, p. 309-323.

Paine, W.R. and A.A. Meyerhoff (1968): Catahoula Formation of western Louisiana and petrographic criteria for fluviatile depositional environment; Jour. Sed. Petrology, Vol. 38, p. 92-113.

Passega, R. (1957): Texture as characteristic of clastic deposition; Am. Assoc. Petrol. Geol. Bull., Vol. 41, p. 1952-1984.

___________ (1964): Grain-size representation by CM patterns as a geological tool; Jour. Sed. Petrology, Vol. 34, p. 830-874.

Pelzer, E.E. (1966): Mineralogy, geochemistry and stratigraphy of Besa River Shale, British Columbia; Bull. Can. Petrol. Geol., Vol. 14, p. 273-321.

Peterson, R.H., D.J. Gauger and R.R. Lankford (1953): Microfossils of the Upper Cretaceous of northeastern Utah and southwestern Wyoming; Utah Geol. Mineral. Surv. Bull. 47, 158 pages.

Pettijohn, F.J. (1957): Sedimentary rocks, 2nd edition; Harper & Bros., New York, 718 pages.

Pfeiffer, N.E. (1922): Monograph of the Isoetaceae; Ann. Missouri Bot. Gard., Vol. 9, p. 79-232, pl. 12-19.

Philip, G. (1968): Mineralogy of the recent sediments of Tigris and Euphrates Rivers and some of the older detrital deposits; Jour. Sed. Petrology, Vol. 38, p. 35-44.

Pierce, J.W. and F.R. Siegel (1969): Quantification in clay mineral studies of sediments and sedimentary rocks; Jour. Sed. Petrology, Vol. 39, p. 187-193.

Potonié, R. (1956): Synopsis der Gattungen der Sporae dispersae, II. Teil: Sporites (Nachtrage), Saccites, Aletes, Praecolpates, Polyplicates, Monocolpates; Beih. Geol. Jahrb., Vol. 31, p. 1-114.

___________ (1958): Synopsis der Gattungen der Sporae dispersae. III. Teil: Nachtrage Sporites, Fortsetzung Pollenites mit Generalregister zu Teil I-III. Beih. Geol. Jahrb., Vol. 39, p. 1-189.

Potonié, R. and G.O.W. Kremp (1954): Die Gattungen der Paleozoischen Sporae dispersae und ihre Stratigraphie; Geol. Jahrb., Vol. 69, p. 111-194.

Potter, P.E. (1967): Sand bodies and sedimentary environments: a review; Bull. Am. Assoc. Petrol. Geol., Vol. 51, p. 337-365.

Powers, M.C. (1953): A new roundness scale for sedimentary particles; Jour. Sed. Petrology, Vol. 23, p. 117-119.

Pryor, W.A. (1960): Cretaceous sedimentation in Upper Mississippi Embayment; Bull. Am. Assoc. Petrol. Geol., Vol. 44, p. 1473-1504.

Rao, A.R. (1943): Jurassic spores and sporangia from Rajmahal Hills, Bihar; Proc. Nat. Acad. Sci. India, sec. B, Vol. 13, pt. 3, p. 181-197.

Rateev, M.A. (1957): Clay minerals and their facial occurrence in water basins of the humid zones; Issled. i Ispol'z Glin, L'vovsk. Gos. Univ., Materialy Soveshch, Lvov, p. 117-132 (in Russian).

Ritchie, W.D. (1957): The Kneehills Tuff; unpublished M.Sc. thesis, Dept. Geology, Univ. of Alberta, 66 pages.

____________ (1960): The Kneehills Tuff; Jour. Alberta Soc. Petroleum Geol., Vol. 8, p. 339-341.

Rizzini, A. and R. Passega (1964): Évolution de la sédimentation et orogenèse, vallée du Santerno Appennin septentrional, in Turbidites, Bouma, A.H., ed.; Elsevier, p. 65-74.

Rosenfeld, W.D. and S.R. Silverman (1959): Carbon isotope fractionation in bacterial production of methane; Science, Vol. 130, p. 1658-1659.

Ross, C.S. and S.B. Hendricks (1945): Minerals of the montmorillonite group; U.S. Geol. Surv. Prof. Paper 205B.

Royse, C.F. (1968): Recognition of fluvial environments by particle-size characteristics; Jour. Sed. Petrology, Vol. 38, p. 1171-1178.

Russell, D.A. and T.P. Chamney (1967): Notes on the biostratigraphy of dinosaurian and microfossil faunas in the Edmonton Formation (Cretaceous) Alberta; Nat. Mus. Can. Natural Hist. Papers, no. 35, 22 pages.

Russell, L.S. (1932): The Cretaceous-Tertiary transition of Alberta; Trans. Roy. Soc. Can. 3rd Ser., Sec. IV, p. 121-156.

____________ (1964): Cretaceous non-marine faunas of northwestern North America; Roy. Ont. Mus., Life Sci. Contrib. 61, 24 pages.

Sahni, B. and H.S. Rao (1943): A silicified flora from the Intertrappean cherts around Sausar in the Deccan; Proc. Nat. Acad. Sci. India, Vol. 13, p. 36-75.

Sahu, B.K. (1964): Depositional mechanisms from the size analysis of clastic sediments; Jour. Sed. Petrology, Vol. 34, p. 73-83.

Sarmiento, R. and R.A. Kirby (1962): Recent sediments of Lake Maracaibo; Jour. Sed. Petrology, Vol. 32, p. 698-724.

Scheere, J. (1955): Des intercalations à sphérolites dans les couches de houille - Mode d'occurrence et conditions de genèse; Publ. Ass. Etud. Paléont. Strat. Houillères, Bruxelles, No. 21, p. 347-356.

Schemel, M.P. (1950): Cretaceous plant microfossils from Iowa; Am. Jour. Botany, Vol. 37, p. 750-754.

Schopf, J.M. (1938): Spores from the Herrin (no. 6) coal bed in Illinois; Illinois Geol. Surv. Rept. Invest. 50, 73 pages.

Selwyn, A.R.C. (1874): Observation in the Northwest Territory, from Fort Garry to Rocky Mountain House; Can. Geol. Surv. Rept. Prog., 1873-74, p. 17-62.

Shafiqullah, M. (1963): Geochronology of Cretaceous-Tertiary boundary, Alberta, Canada; unpublished M.Sc. thesis, Dept. Geology, Univ. of Alberta.

Singh, C. (1964): Microflora of the Lower Cretaceous Mannville Group, east-central Alberta; Res. Coun. Alberta Bull. 15, 238 pages.

Sitholey, R.V. (1943): Plant remains from the Triassic of the Salt Range in the Punjab; Proc. Nat. Acad. Sci. India, Vol. 13, p. 300-327.

Snead, R.G. (1969): Microfloral diagnosis of the Cretaceous-Tertiary boundary, central Alberta; Res. Coun. Alberta Bull. 25, 148 pages.

Srivastava, S.K. (1965): Palynology of Late Cretaceous mammal-beds, Scollard, Alberta; unpublished M.Sc. thesis, Dept. Geology, Univ. of Alberta, 129 pages.

________________ (1966): Upper Cretaceous microflora (Maestrichtian) from Scollard, Alberta, Canada; Pollen et Spores, Vol. 8, p. 492-552.

________________ (1967): Palynology of Late Cretaceous mammal-beds, Scollard, Alberta (Canada); Palaeog. Palaeoclim. Palaeoecol., Vol. 3, p. 133-150.

_______________ (1968a): Angiospermic microflora of the Edmonton Formation, Alberta, Canada; unpublished Ph.D. thesis, Dept. Geology, Univ. Alberta, 342 pages.

_______________ (1968b): Fungal elements from the Edmonton Formation (Maestrichtian), Alberta, Canada; Can. Jour. Botany, Vol. 46, p. 1115-1118.

_______________ (1968c): Eight species of Mancicorpus from the Edmonton Formation (Maestrichtian), Alberta, Canada; Can. Jour. Botany, Vol. 46, p. 1485-1490.

_______________ (1968d): Azolla from the Upper Cretaceous Edmonton Formation, Alberta, Canada; Can. Jour. Earth Sci., Vol. 5, p. 915-919.

_______________ (1969): New spinulose Aquilapollenites spp. from the Edmonton Formation (Maestrichtian), Alberta, Canada; Can. Jour. Earth Sci., Vol. 6, p. 133-144.

Srivastava, S.K. and P.L. Binda (1969): Megaspores of the genus Balmeisporites from the Upper Cretaceous of Alberta and Saskatchewan, Canada; Rev. Micropaleont., Vol. 11, p. 205-209.

Stanley, E.A. (1965): Upper Cretaceous and Paleocene plant microfossils and Paleocene Dinoflagellates and Hystrichosphaerids from northwestern South Dakota; Bull. Am. Paleont., Vol. XLIX, p. 1-384.

Sternberg, C.M. (1947): The Upper part of the Edmonton Formation of the Red Deer Valley, Alberta; Geol. Surv. Can. Paper 47-1, 11 pages.

Taugourdeau-Lantz, J. and C. Rosset (1966): Sur un nouveau microfossile incertae sedis de l'Oligocene du Bassin de Narbonne; Rev. Micropaleont., Vol. 9, p. 186-191.

Thorarinsson, S. (1954): The tephra-fall from Hekla on March 29, 1947; in The eruption of Hekla 1947-48, part 2, 3; Societas Scientiarum Islandica, Reykjavik, 68 pages.

Tozer, E.T. (1952): The St. Mary River-Willow Creek contact on Oldman River, Alberta. Geol. Surv. Can. Paper 52-3, 9 pages.

__________ (1953): The Cretaceous-Tertiary transition in southwestern Alberta; in Alberta Soc. Petroleum Geol., 3rd Ann. Field Conf. and Symposium, p. 23-31.

Travis, R.B. (1955): Classification of rocks; Colorado School of Mines, Quart., Vol. 58, 98 pages.

Tschudy, R.H. (1961): Palynomorphs as indicators of facies environments in Upper Cretaceous and Lower Tertiary strata, Colorado and Wyoming; in Symposium on Late Cretaceous Rocks of Wyoming, Wyoming Geol. Assoc. Guidebook, p. 53-59.

Tyrrell, J.B. (1886): Report on a part of northern Alberta and portions of the adjacent districts of Assiniboia and Saskatchewan; Geol. Surv. Can. Ann. Rept, Vol. 2, 176 pages.

Udden, J. (1898): Mechanical composition of wind deposits; Augustana Library publ., Vol. 1, 69 pages.

_________ (1914): Mechanical composition of clastic sediments; Bull. Geol. Soc. Am., Vol. 25, p. 655-744.

U.S. Waterways Experiment Station (1939): Studies of materials in suspension in the Mississippi River. U.S. Waterways Exp. Sta., Vicksburg, Miss., Tech. Memo 122-I.

Van Andel, Tj.H. and H. Postma (1954): Recent sediments of the Gulf of Paria. Reports of the Orinoco Shelf Expedition, Vol. I, Verh. Kon. Ned. Akad. van Wetenschappen, Afd. Natuurkunde, Vol. 20, 245 pages.

Vangerow, E.F. (1954): Megasporen und anders pflanzliche mikrofossilien aus der Aachener Kreide; Palaeontographica, Band 96, Abt. B, p. 24-38.

Van Meel, L. (1953): Contribution a l'edude du Lac Upemba. A.-Le milieu physico-chimique; Ints. Parcs Nat. Congo Belge, Bruxelles, fasc. 9.

Vishnu-Mittre, (1954): Petrified spores and pollen grains from the Jurassic rocks of Rajmahal Hills, Bihar; Palaeobotanist, Vol. 3, p. 117-127.

Warner, M.M. (1966): Sedimentational analysis of the Duchesne River Formation, Uinta Basin, Utah; Bull. Geol. Soc. Am., Vol. 77, p. 945-958.

Warshaw, C.M. and R. Roy (1961): Classification and a scheme for the identification of layer silicates; Bull. Geol. Soc. Am., Vol. 72, p. 1455-1492.

Weaver, C.E. (1956): The distribution and identification of mixed layer clays in sedimentary rocks; Am. Mineral., Vol. 41, p. 202-221.

____________ (1958): Geologic interpretation of argillaceous sediments; Bull. Am. Assoc. Petrol. Geol., Vol. 42, p. 254-271.

Weber, J.N., E.G. Williams and M.L. Keith (1964): Paleoenvironmental significance of carbon isotopic composition of siderite nodules in some shales of Pennsylvanian age; Jour. Sed. Petrology, Vol. 34, p. 814-818.

Weller, J.M. (1960): Stratigraphic principles and practice; Harper and Row, New York, 725 pages.

EXPLANATION OF PLATE I

(All illustrations magnified X100, unless otherwise indicated).

Figures 1, 2: *Triletes srivastavae* sp. nov. (Holotype: fig. 1).

Figures 3-5: *Minerisporites mirabilis* (Miner) Potonié.

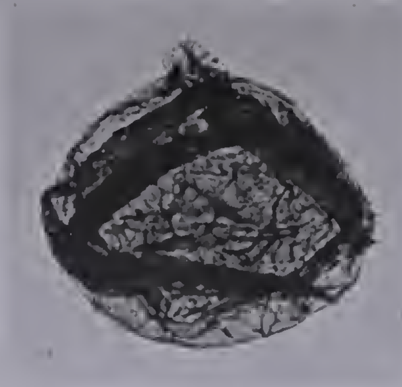
Figures 6-10: *Warrenisporites spinosus* gen. et sp. nov. (Holotype: figs. 6, 9); 9, 10 - details X260.

Figures 11-13: *Erlansonisporites singhii* sp. nov. (Holotype: figs. 11, 12); 12 - detail X625.

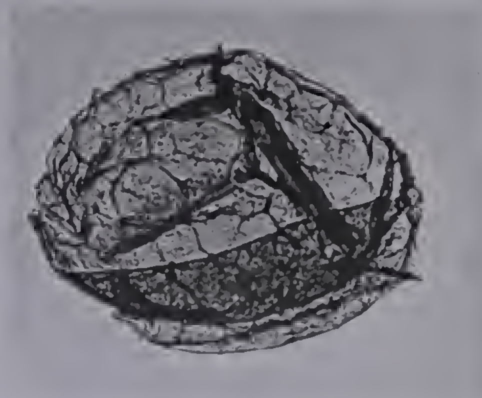
PLATE I

1

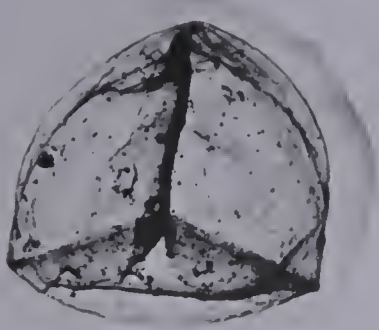
3



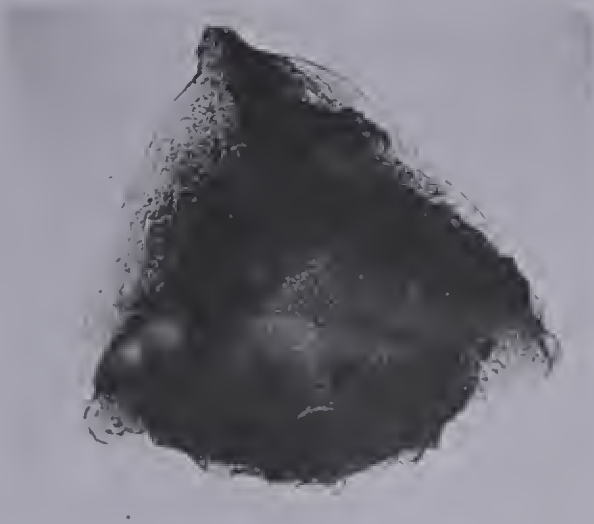
4



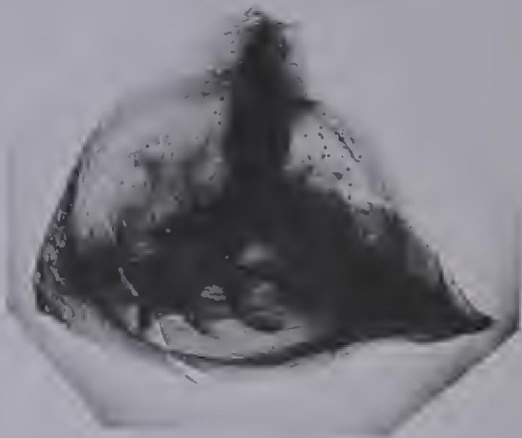
5



2

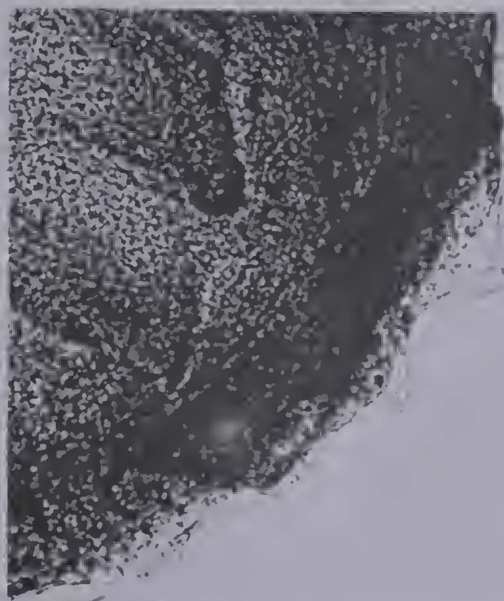


6

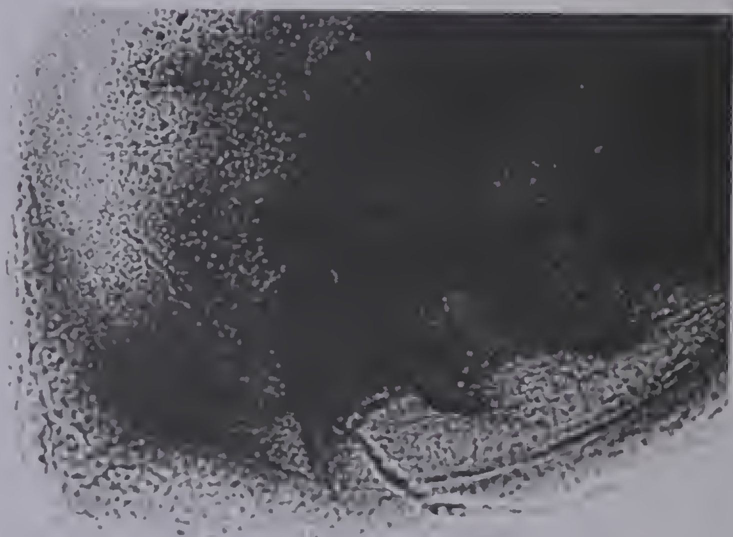


7

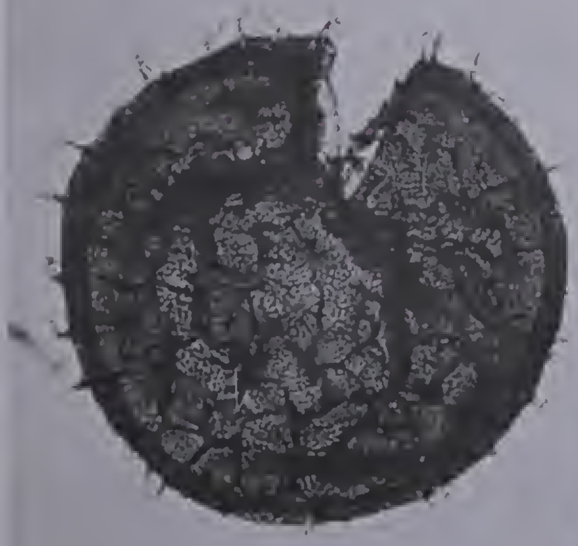
8



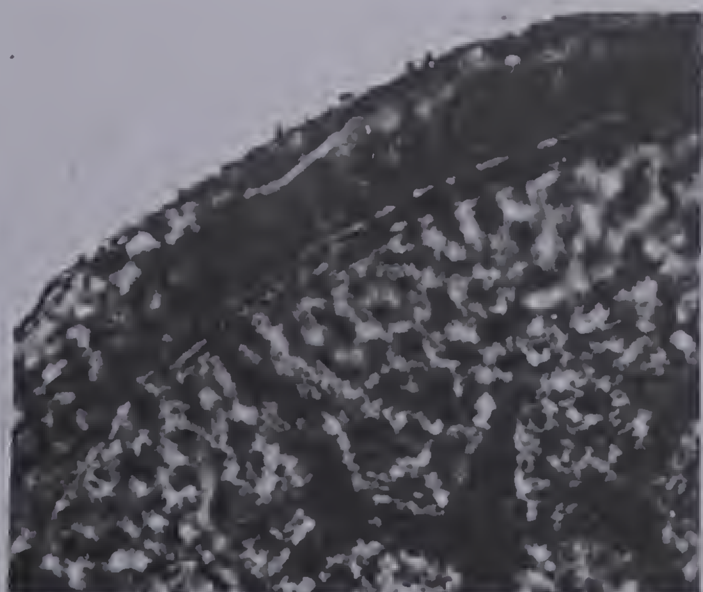
9



10



11



12

13

EXPLANATION OF PLATE II

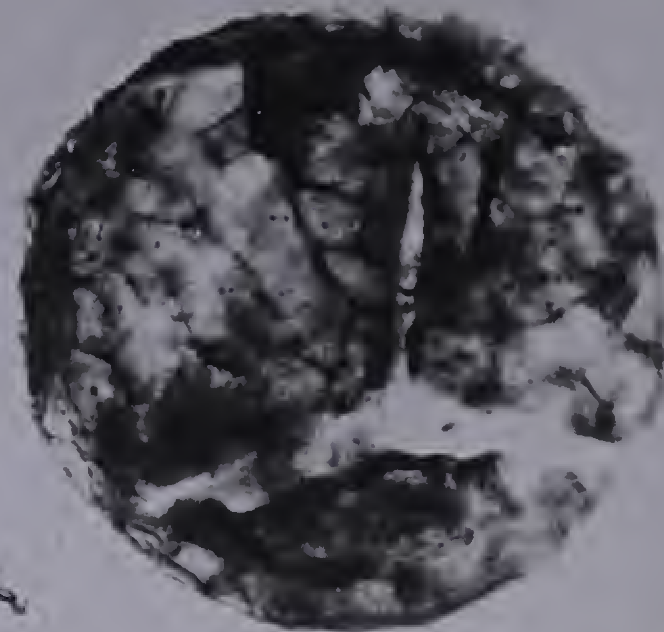
(All illustrations magnified X100, unless otherwise indicated).

Figures 1-4: *Erlansonisporites augustus* sp. nov. (Holotype: figs. 1, 3); 3 - detail X160.

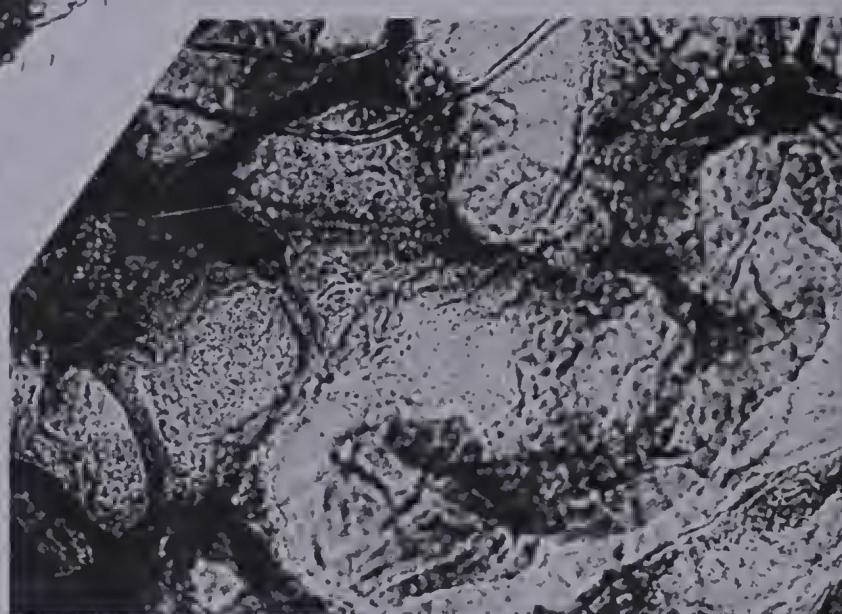
Figure 5: *Erlansonisporites* sp.

PLATE II

1

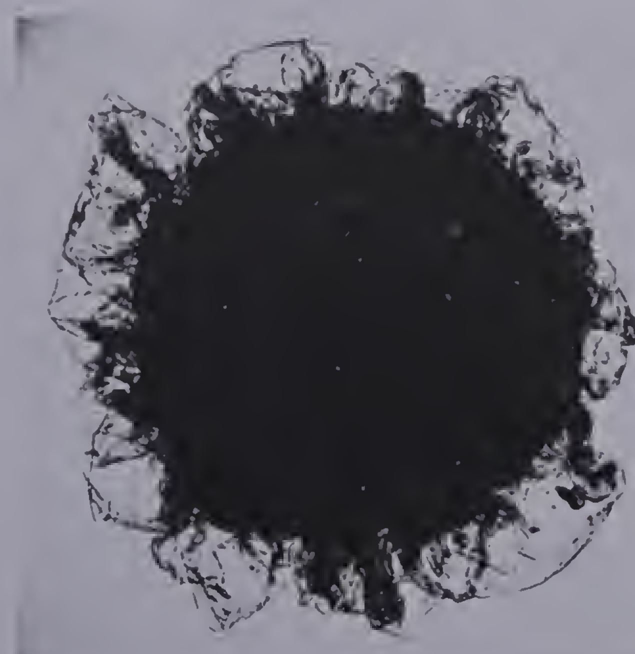


2



3

4



5

EXPLANATION OF PLATE III

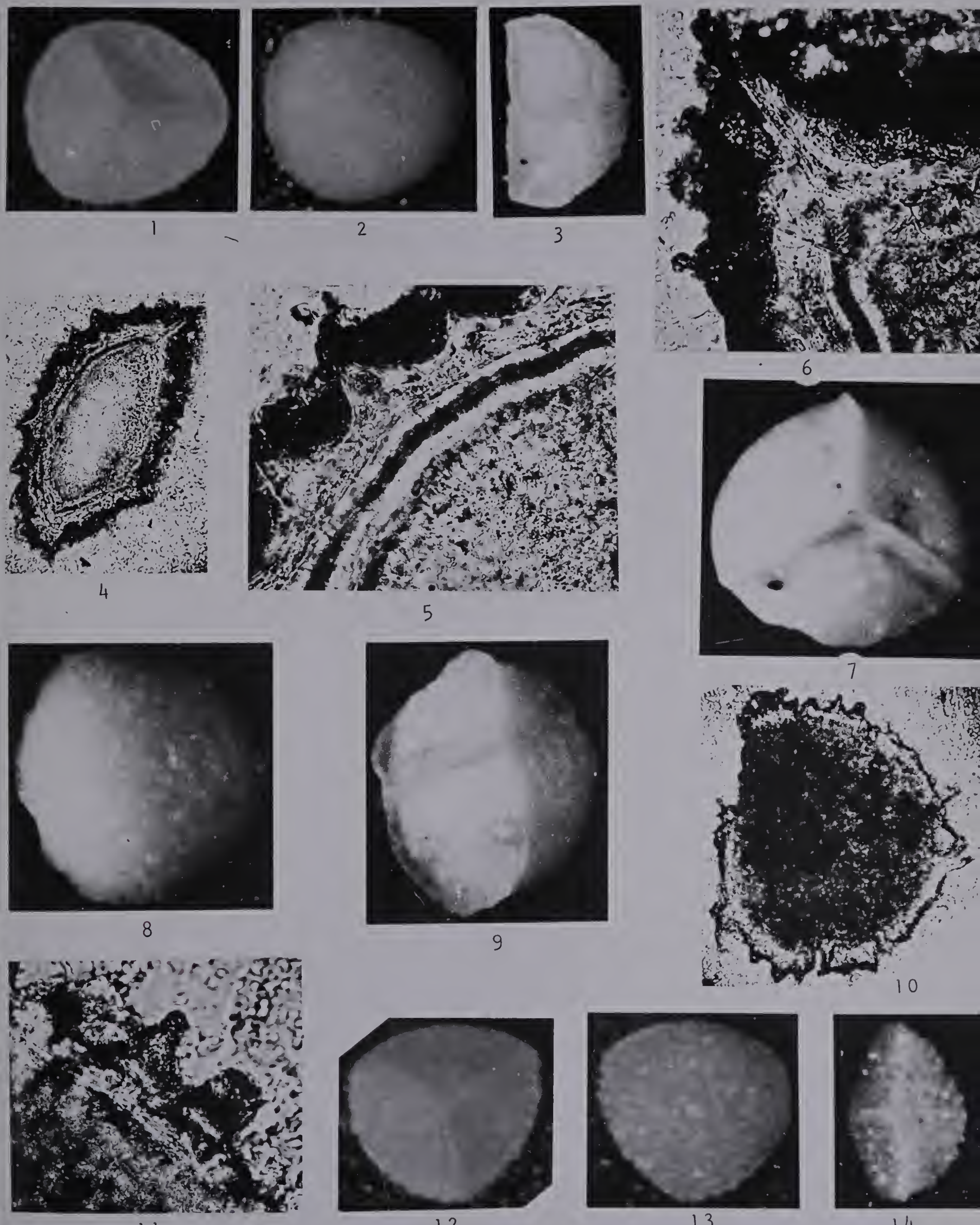
(All illustrations magnified X100, unless otherwise indicated).

Figures 1-6: *Henrisporites granulatus* Binda and Srivastava. (Holotype: figs. 1-3); 1 - proximal view; 2 - distal view; 3 - lateral view; 4 - section through equatorial axis X117; 5,6 - details of spore wall X440.

Figures 7-11: *Henrisporites elkwaterensis* Binda and Srivastava. (Holotype: figs. 7-9); 7 - proximal view; 8 - distal view; 9 - lateral view; 10 - section through the equatorial axis X117; 11 - details of the spore wall X440.

Figures 12-14: *Verrutriletes albertensis* Binda and Srivastava. (Holotype); 12 - proximal view; 13 - distal view; 14 - lateral view.

PLATE III



EXPLANATION OF PLATE IV

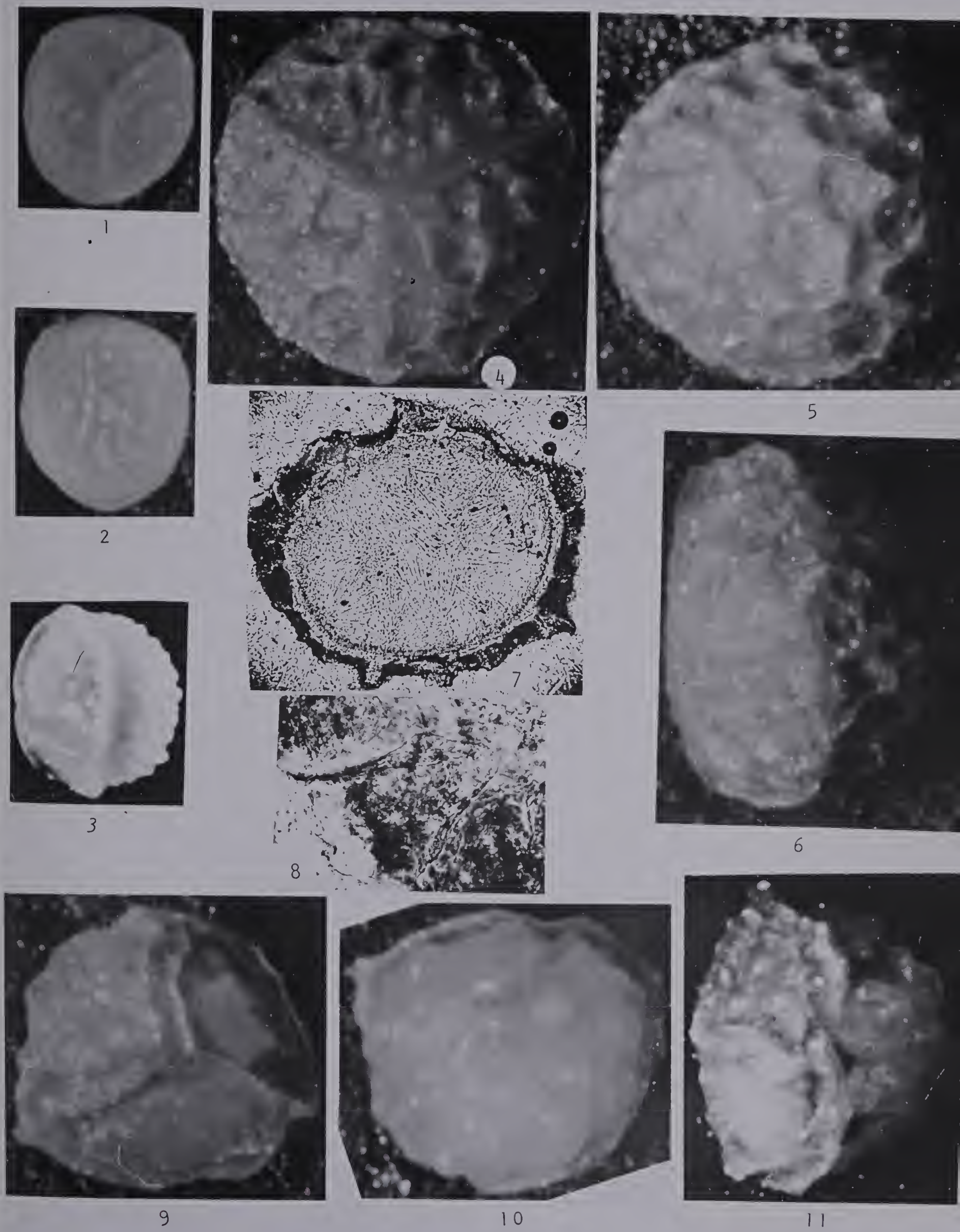
(All illustrations magnified X100, unless otherwise indicated).

Figures 1-3: *Henrisporites sheilae* Binda and Srivastava (Holotype). 1 - proximal view; 2 - distal view; 3 - lateral view.

Figures 4-8: *Horstisporites canadensis* Binda and Srivastava (Holotype: figs. 4-6); 4 - proximal view; 5 - distal view; 6 - lateral view; 7 - section through equatorial axis X117; 8 - details of the spore wall X440.

Figures 9-11: *Stelckisporites standardensis* Binda and Srivastava (Holotype); 9 - proximal view; 10 - distal view; 11 - lateral view.

PLATE IV



EXPLANATION OF PLATE V

(All illustrations magnified X100, unless otherwise indicated).

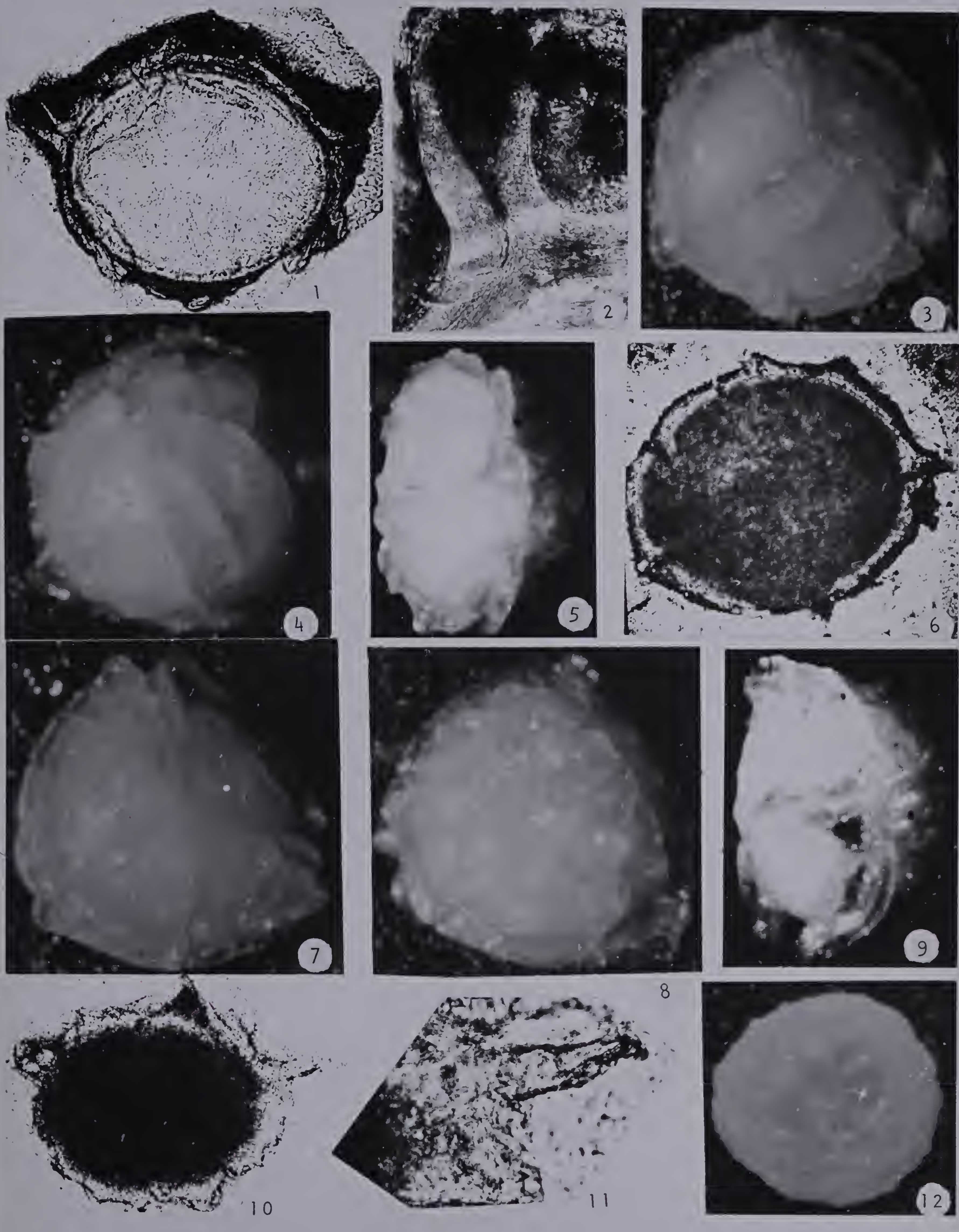
Figures 1, 2: _Stelckisporites standardensis_ Binda and Srivastava.
1 - section through equatorial axis X117;
2 - details of the spore wall X440.

Figures 3-6: _Stelckisporites tenuistriatus_ Binda and Srivastava (Holotype: figs. 3-5); 3 - proximal view; 4 - distal view; 5 - lateral view; 6 - section through equatorial axis X117.

Figures 7-11: _Stelckisporites verrucosus_ Binda and Srivastava (Holotype: figs. 7-9); 7 - proximal view; 8 - distal view; 9 - lateral view; 10 - section through equatorial axis X117; 11 - details of the spore wall X440.

Figure 12: _Selenasporites reticulatus_ Binda and Srivastava (Holotype).

PLATE V



EXPLANATION OF PLATE VI

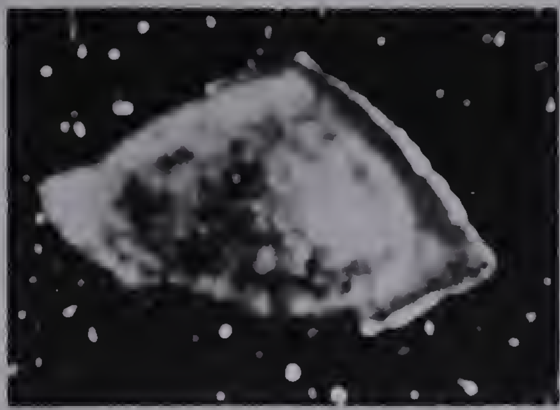
Figures 1-8: Fragments of silicified megaspores X100.

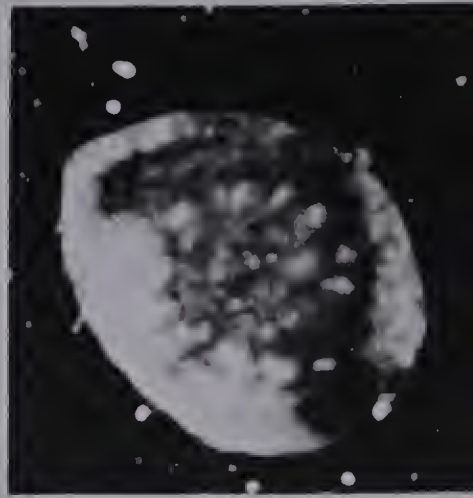
Figures 9-11: Unidentified silicified vegetal fragments X260.

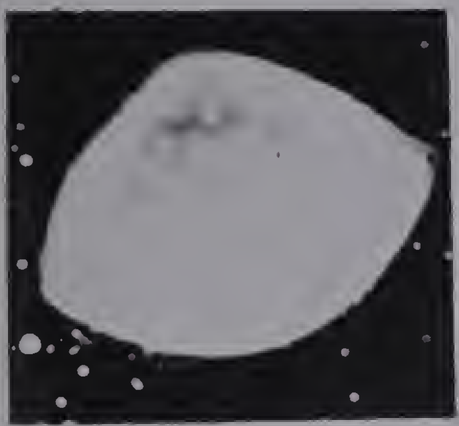
Figure 12: Silicified spore? X260.

PLATE VI


1


2


3

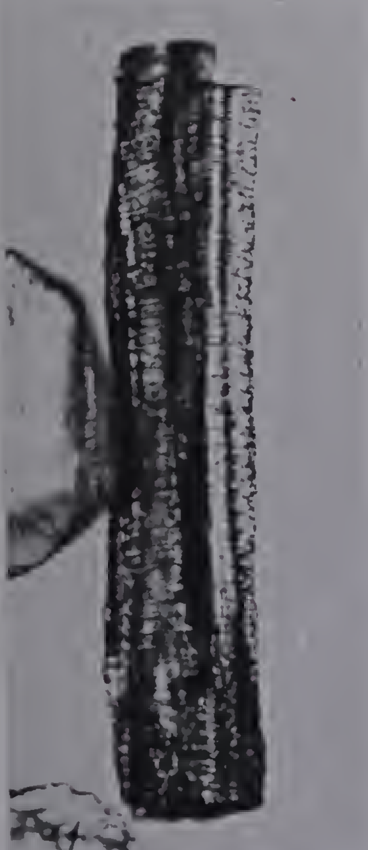

4


5


6

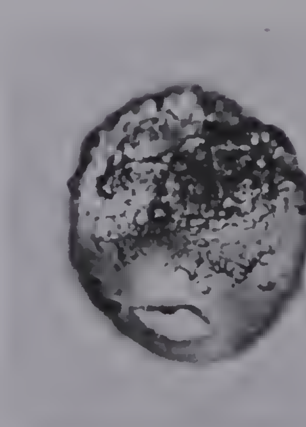

7


8


9


10


11


12

EXPLANATION OF PLATE VII

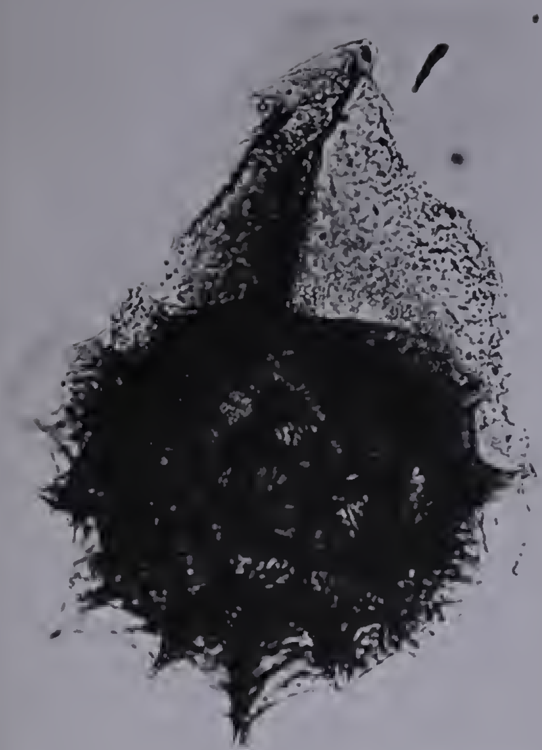
Figures 1-3: _Balmeisporites bellus_ Kondinskaya. 1 - X250; 2, 3 - details X1000.

Figures 4-6: _Balmeisporites canadensis_ Srivastava and Binda (Holotype); 4 - X200; 5 - X250; 6 - detail X1000.

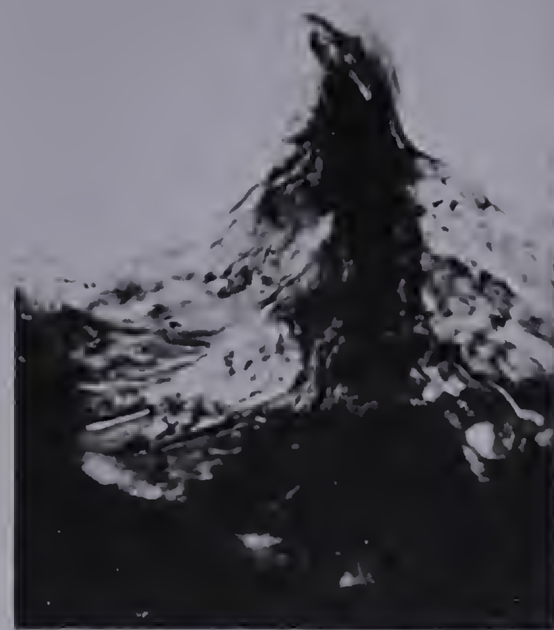
Figure 7: _Balmeisporites kondinskayae_ Srivastava and Binda (Holotype); X250.

Figures 8, 9: _Balmeisporites densireticulatus_ sp. nov. (Holotype); 8 - double time of exposure X225; 9 - detail X 625.

PLATE VII



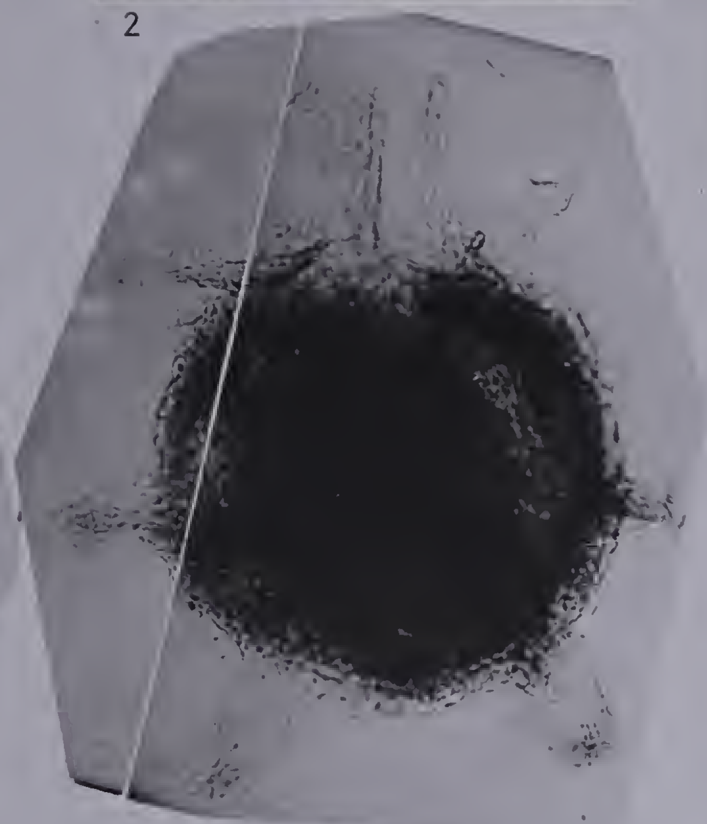
1



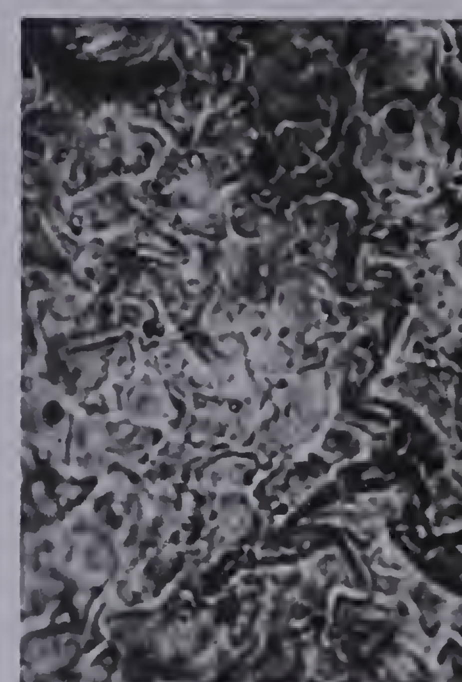
2

3

4



5



6

7

8

9

EXPLANATION OF PLATE VIII

Figures 1, 2: Balmeisporites densireticulatus sp. nov. (Holotype); 1 - detail of acrolamellae X400; 2 - detail X400.

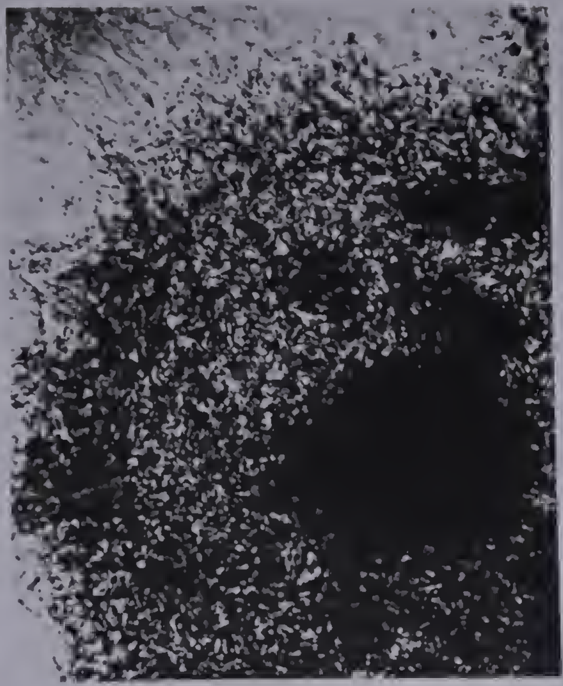
Figures 3, 4: Balmeisporites sp.; 3 - X250; 4 - detail X400.

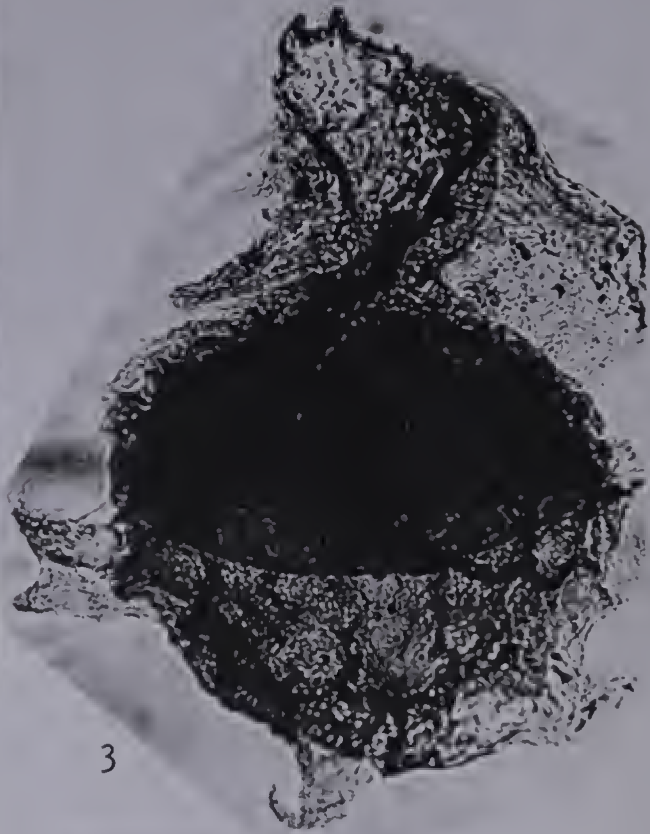
Figures 5, 8: Megaspore type A; 5 - X100; 8 - detail of appendages X160.

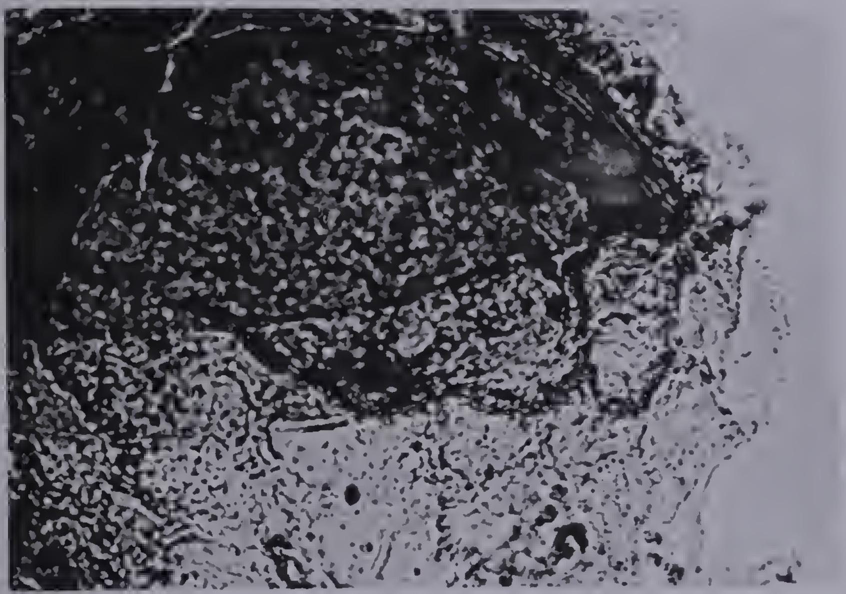
Figures 6, 7: Megaspore type B; 6 - X100; 7 - detail of appendages X400.

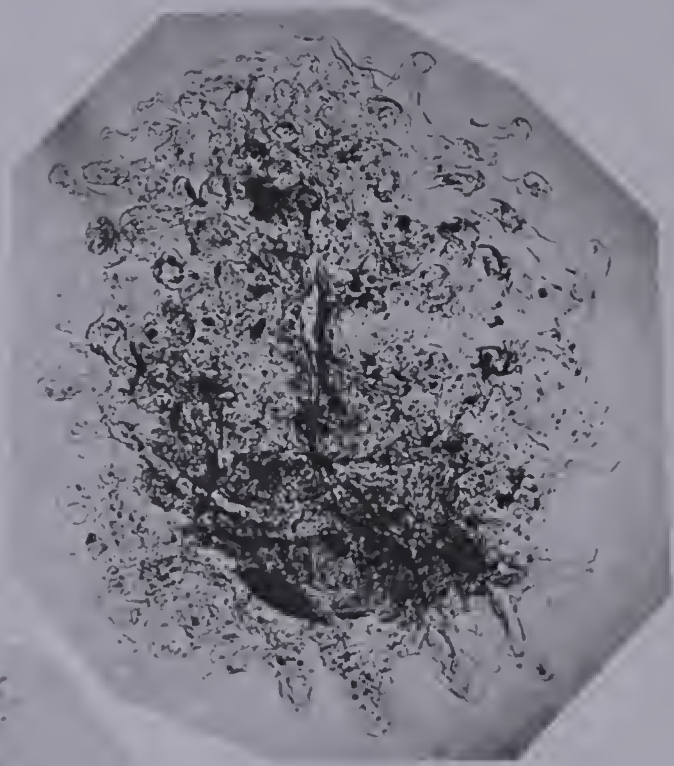
PLATE VIII


1

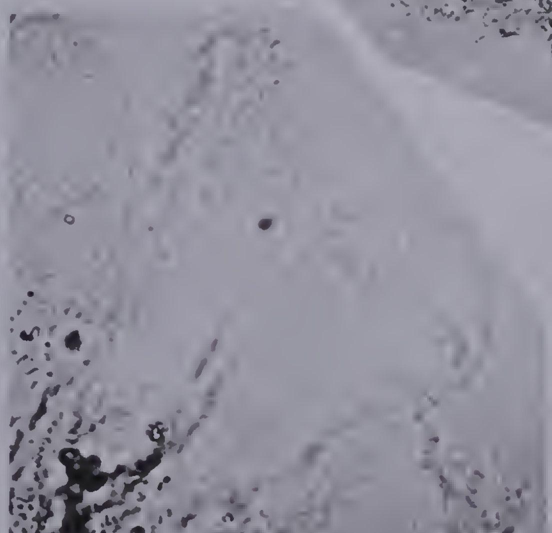

2


3


4


5


6


7


8

EXPLANATION OF PLATE IX

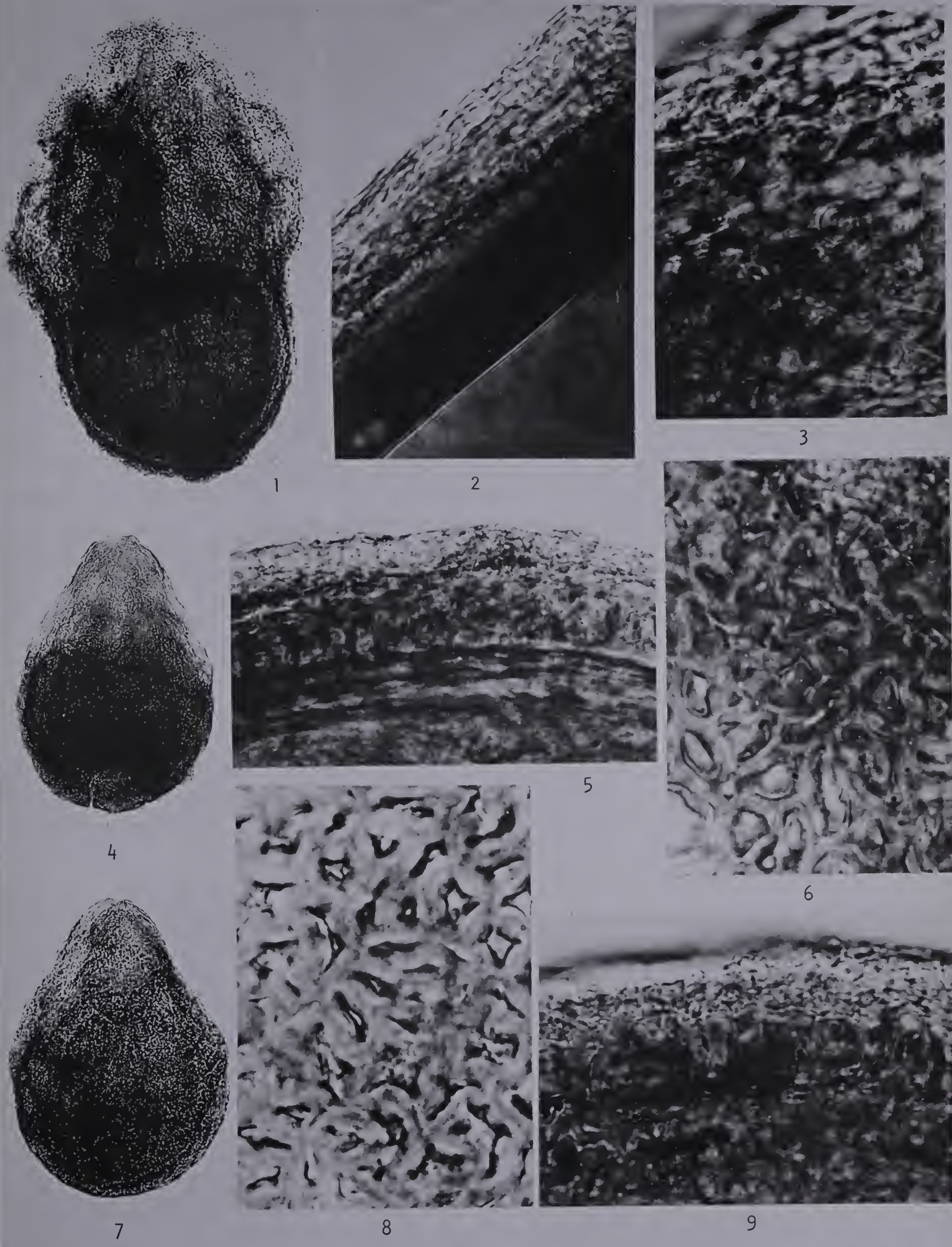
(All illustrations magnified X100, unless otherwise indicated).

Figures 1-3: _Azolla_ sp. A; 2 - detail of perispore wall X1000. 3 - detail showing fibrils X1000.

Figures 4-6: _Azolla_ sp. B; 5 - detail of perispore wall X1000; 6 - detail of perispore ornamentation X1600.

Figures 7-9: _Azolla_ sp. C; 8 - detail of perispore ornamentation X1600; 9 - detail of perispore wall X1000.

PLATE IX



EXPLANATION OF PLATE X

(All illustrations magnified X100, unless otherwise indicated).

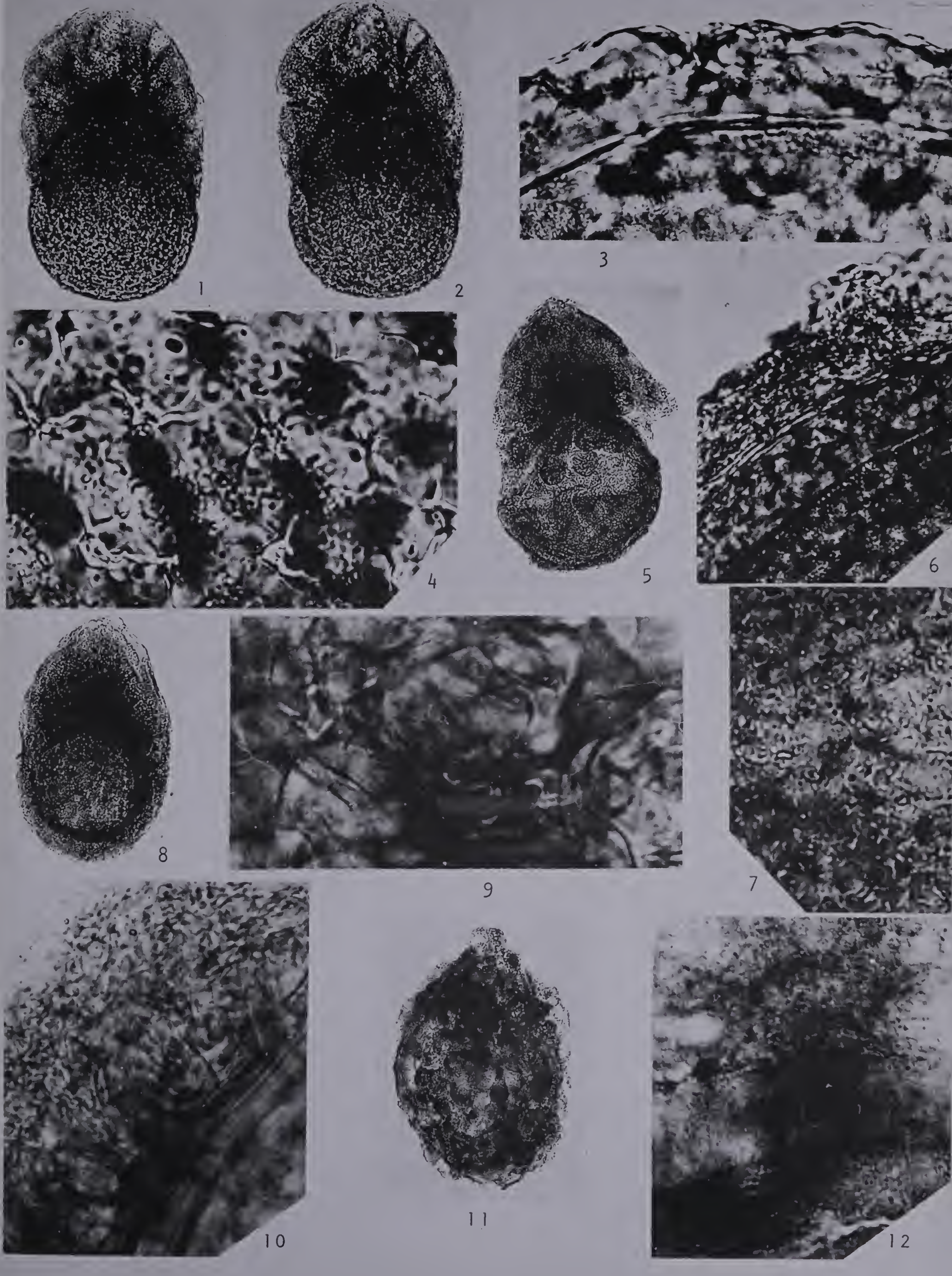
Figures 1-4: Azolla sp. D; 1 - low focus; 2 - high focus; 3 - detail of perispore wall X1000; 4 - detail of perispore ornamentation X1275.

Figures 5-7: Azolla sp. E; 6 - detail of perispore wall X1000; 7 - detail of perispore ornamentation X1600.

Figures 8-10: Azolla sp. F; 9 - detail of perispore ornamentation X1600; 10 - detail of perispore wall X1000.

Figures 11, 12: Azolla sp. G; 12 - detail of perispore wall X1000.

PLATE X



EXPLANATION OF PLATE XI

(All illustrations magnified X100, unless otherwise indicated).

Figures 1-3: _Spermatites piperiformis_ Binda (Holotype: figs 1, 2); 2 - detail of the wall X400.

Figure 4: _Juncus alpinus_ (modern seed).

Figures 5-7: _Spermatites minimus_ Binda (Holotype: figs. 5, 6); 6 - detail X400).

Figure 8: _Juncus bufonius_ (modern seed).

Figures 9-11: _Spermatites ellipticus_ Miner subspecies _minor_ Binda (Holotype: figs. 9, 10); 10 - detail of the wall X400.

Figure 12: _Juncus alpinus_ (modern seed).

PLATE XI

EXPLANATION OF PLATE XII

(All illustrations magnified X100, unless otherwise indicated).

Figures 1, 2: *Spermatites saskatchewanicus* sp. nov. (Holotype: fig. 1).

Figure 3: *Spermatites pinguis* sp. nov. (Holotype).

Figure 4: *Spermatites robustus* sp. nov. (Holotype).

Figures 5, 6: *Juncus balticus* (modern seed); 6 - detail of the wall X260.

Figure 7: *Spermatites nanus* Miner.

PLATE XII

EXPLANATION OF PLATE XIII

(All illustrations magnified X50, unless otherwise indicated).

Figures 1-5: *Costatheca striata* (Dijkstra) Hall; 4 - detail X126;
5 - section perpendicular to long axis X330.

Figures 6-8: *Costatheca minerii* sp. nov. (Holotype: figs. 6, 7);
6 - detail X126.

PLATE XIII

EXPLANATION OF PLATE XIV

(All illustrations magnified X50, unless otherwise indicated).

Figure 1: *Costatheca inflata* sp. nov. (Holotype).

Figure 2: *Costatheca exilis* (Vangerow) Hall 1967.

Figures 3-5: *Costatheca pusilla* sp. nov. (Holotype: fig. 3).

Figures 6, 7: *Costatheca lata* (Vangerow) Hall 1967.

Figures 8, 9: *Carpotheca elegans* gen. et sp. nov. (Holotype);
9 - detail of the wall X330.

Figures 10, 11: *Carpotheca coronata* sp. nov. (Holotype: fig. 10)

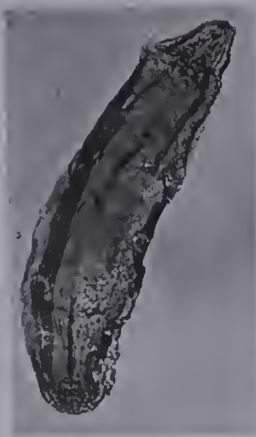
Figure 12: *Carpotheca parva* sp. nov. (Holotype).

Figures 13, 14: *Carpotheca falcata* sp. nov. (Holotype: fig. 13)

PLATE XIV

1

2



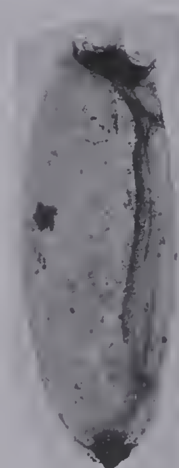
3

4

5

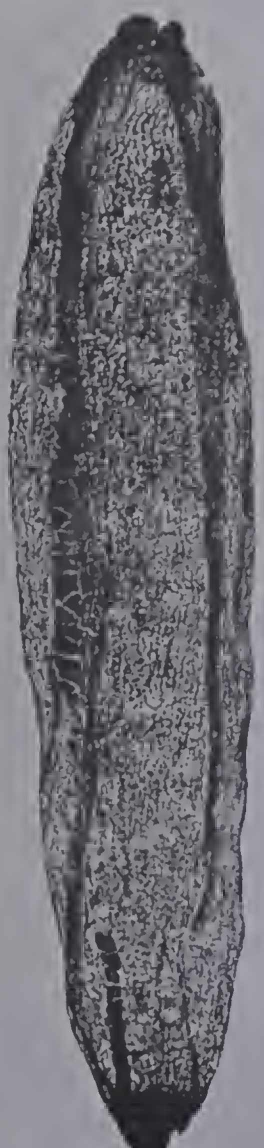
6

7



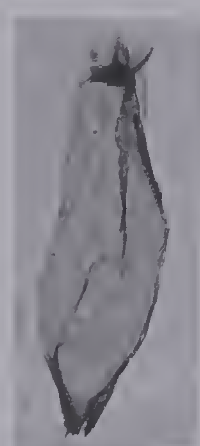
10

13



8

9



11

12

14

EXPLANATION OF PLATE XV

Slide No. RC/V5, Wizard Lake, crossed nicols, X52. Photomicrograph of claystone of the Battle Member of the Edmonton Formation showing irregular thin layers of montmorillonitic clay and abundance of silt-size grains. Most of the grains that appear black in the photograph are opaline vegetal microfossils.

PLATE XV

EXPLANATION OF PLATE XVI

Photomicrographs of samples from the Battle Member of the Edmonton Formation.

A: Slide No. RC/V4, Wizard Lake, parallel nicols, X25. Alternating bands of montmorillonite and detrital elements including quartz grains, more or less devitrified glass shards, and silicified vegetal remains.

B: Slide No. RC/V4, Wizard Lake, parallel nicols, X62.5. Lobate masses of montmorillonite, and detrital elements. Glass shards are visible in the upper left corner.

C: Slide No. RC/V5, Wizard Lake, parallel nicols, X100. Silicified vegetal fragments in clay matrix.

D: Slide No. RC/V4, Wizard Lake, parallel nicols, X100. Silicified vegetal fragments in clay matrix. A fungal sporangium is recognizable in the upper left corner, a tracheid in the lower right corner.

E and F: Slide No. G5, Gleichen, parallel nicols, X400. Silicified pollen grains and spores showing well preserved ornamentation. The trilete mark is visible in the spore in the upper right corner of fig. F.

G: Slide No. RC/V4, Wizard Lake, parallel nicols, X400. Silicified pollen and spore. The grain on the right could possibly be a bisaccate pollen.

H: Slide No. M21bis, Scollard, parallel nicols, X255. Photomicrograph of a bentonite associated with the Kneehills Tuff bed showing a great abundance of glass shards. The short cylindrical element in the center of the field is a tracheid.

I: Slide No. M21bis, Scollard, parallel nicols, X625. Magnification of volcanic glass shards.

PLATE XVI

EXPLANATION OF PLATE XVII

Kneehills Tuff bed

A and B: Zeolites and clay in hand-specimens from the Kneehills Tuff bed (scale in centimeters).

C, D, E, F: Photomicrographs of samples of Kneehills Tuff bed showing a decreasing grain-size from C to F (south to north). All photographs in crossed nicols and X40.
C: slide No. X1, Oldman River.
D: slide No. S-TUFF, Quarry 45, Cypress Hills.
E: slide No. U30, Nevis Bridge.
F: slide No. Z4, Whitecourt.

G: Slide No. S-TUFF, Quarry 45, parallel nicols, X255. Magnification of partly devitrified glass-shards, tracheary elements, and a short bipyramidal "volcanic" quartz.

H: Slide No. U30, Nevis Bridge, parallel nicols, X255. Magnification of glass shards and a well-preserved silicified tracheary element.

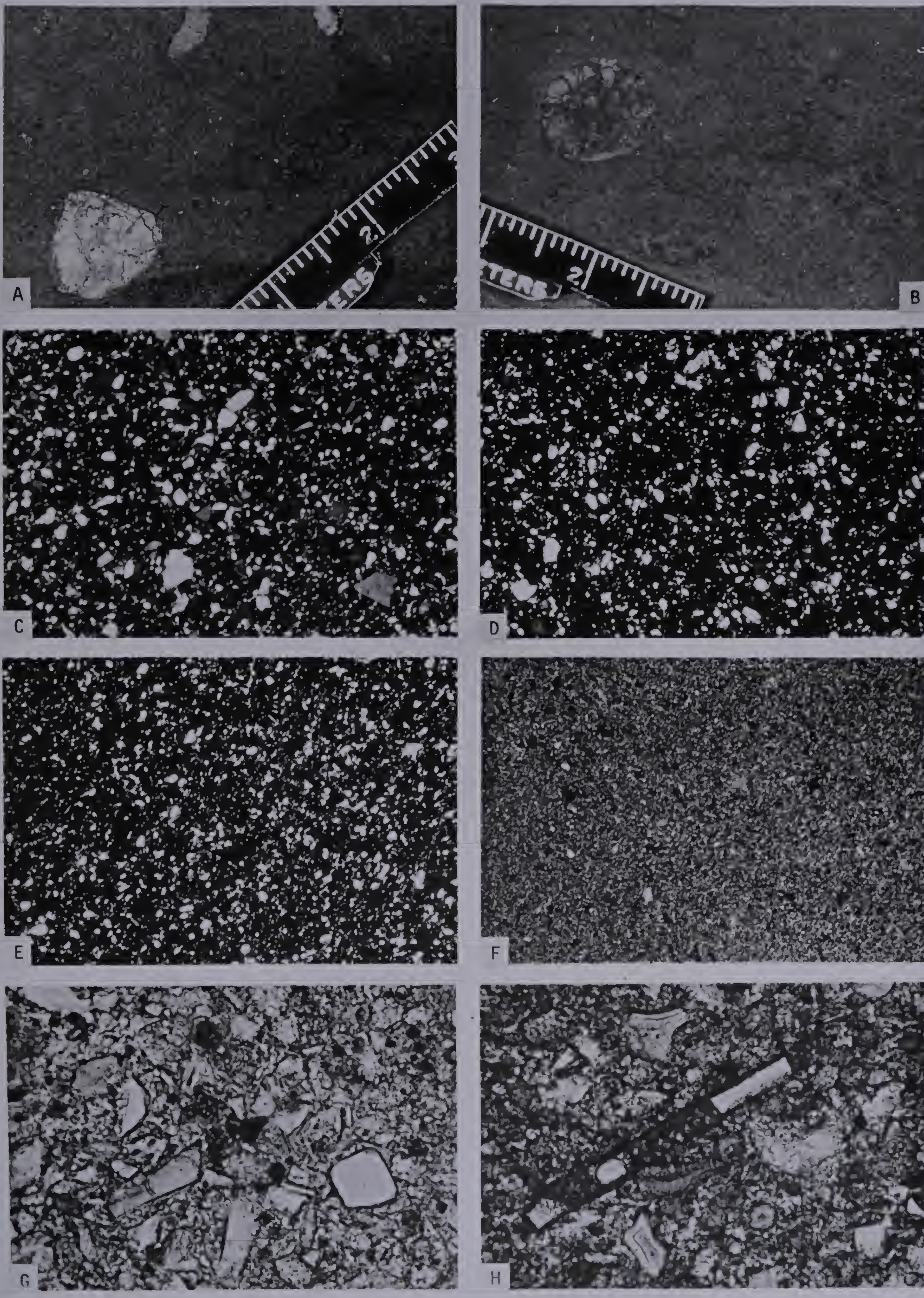


PLATE XVII

EXPLANATION OF PLATE XVIII

Photomicrographs of sandstones of the Middle Edmonton Formation

A: Slide No. RC/S38, Wizard Lake, parallel nicols, X25.

B: Slide No. U10, Nevis Bridge, parallel nicols, X25. Notice the abundance of rock fragments.

C: Slide No. A19, Horseshoe Canyon, crossed nicols, X25.

D and E: Slide No. RC/S40, Wizard Lake, crossed nicols, X50.

F: Slide No. D11, Big Valley, crossed nicols, X100. Authigenic clay (montmorillonite?) forming on sand grains.

G: Slide No. U10, Nevis Bridge, crossed nicols, X100. Montmorillonite cement (m).

H: Slide No. A18, Horseshoe Canyon, crossed nicols, X100. Kaolinite cement (k).

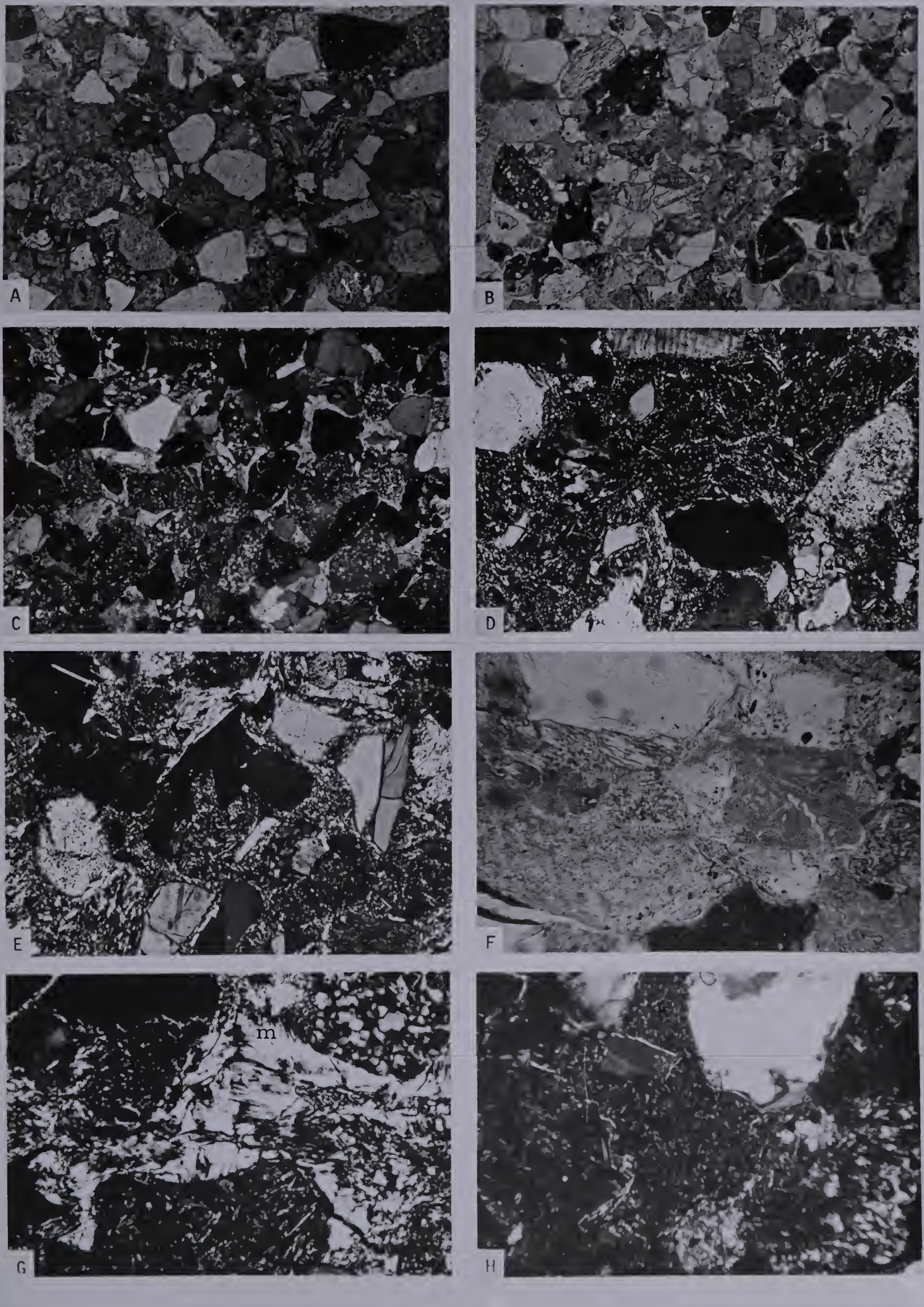


PLATE XVIII

EXPLANATION OF PLATE XIX

Photomicrographs of individual grains from sandstones of the Middle Edmonton Formation

A: Slide No. A19, Horseshoe Canyon, crossed nicols, X160. Polycrystalline quartz grain with straight contacts between equant or sub-equant interlocking crystals. Grains of this type are most commonly released by plutonic rocks.

B: Slide No. D11, Big Valley, crossed nicols, X160. Polycrystalline quartz grain with sutured contacts between individual crystals showing a bimodal size distribution. Grains of this type are most often derived from metamorphic (gneiss) rocks.

C: Slide No. A18, Horseshoe Canyon, crossed nicols, X160. Polycrystalline quartz grain with crenulated contacts between elongated individual crystals. Grains of this type are usually derived from metamorphic (schist) rocks.

D: Slide No. A18, Horseshoe Canyon, crossed nicols, X160. Sedimentary or polycyclic quartz grain.

E: Slide No. U10, Nevis Bridge, crossed nicols, X160. Quartz grain with vermicular chloritic inclusions. Vermicular chlorite is very diagnostic of hydrothermal quartz.

F: Slide No. D1, Big Valley, crossed nicols, X160. Grain displaying myrmekitic intergrowth of albitic plagioclase and quartz.

G: Slide No. A18, Horseshoe Canyon, crossed nicols, X160. Broken fresh plagioclase grain veined by calcite cement.

H: Slide No. RC/S40, Wizard Lake, cross nicols, X100. Volcanic rock fragment displaying laths of feldspar in a glassy groundmass.

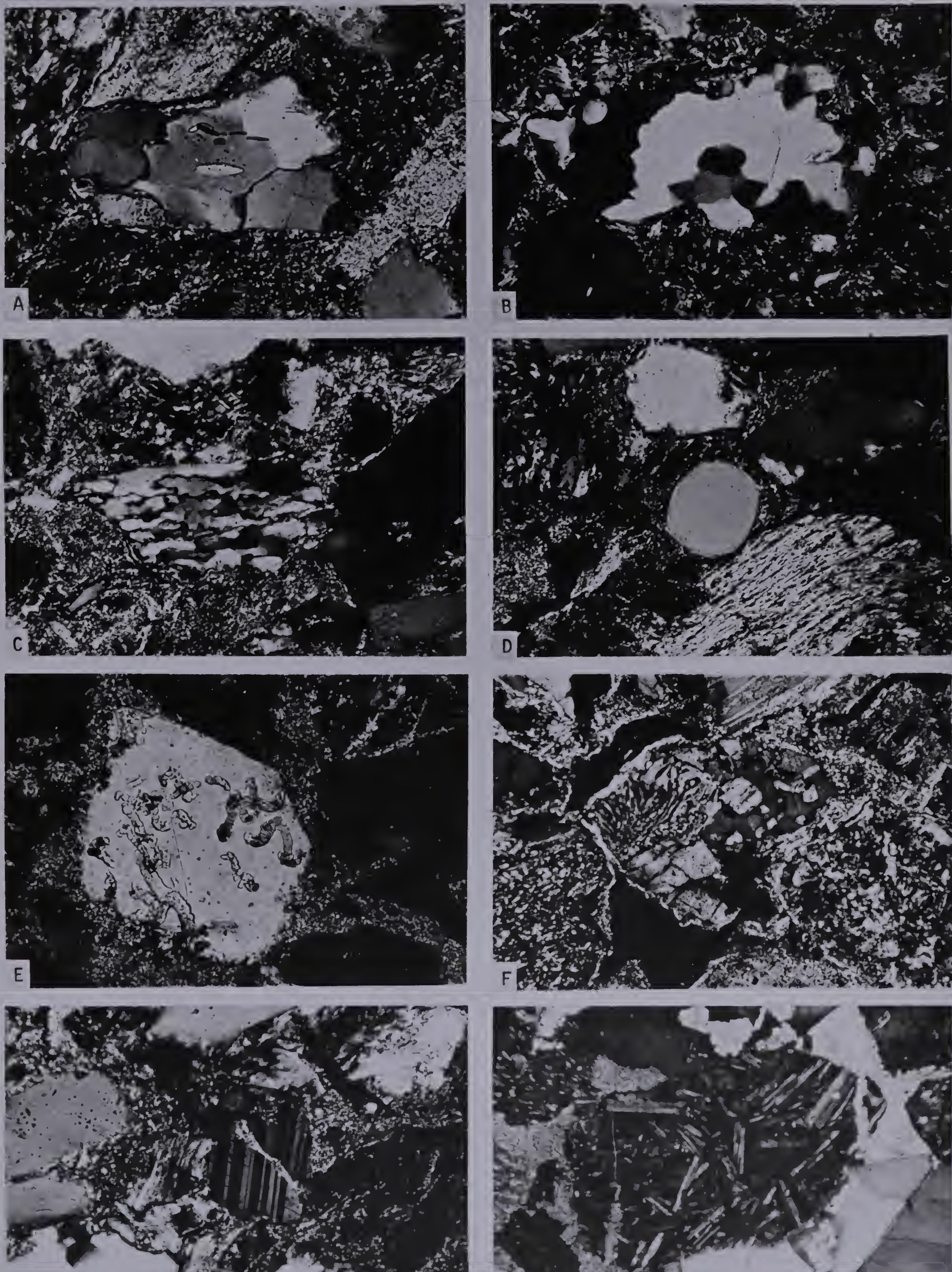


PLATE XIX

EXPLANATION OF PLATE XX

Photomicrographs of sandstones and siltstones of the Middle Edmonton Formation

A: Slide No. RC/S40, Wizard Lake, parallel nicols, X100. Sand-size siltstone fragment.

B: Slide No. RC/S40, Wizard Lake, parallel nicols, X100. Chert fragment with unidentified microfossil (possibly Radiolarian).

C: Slide No. RC/S41, Wizard Lake, parallel nicols, X250. Chert fragment with unidentified microfossil.

D: Slide No. RC/S40, Wizard Lake, parallel nicols, X250. Chert fragment with unidentified microfossil.

E: Slide No. D1, Big Valley, parallel nicols, X160. Chert fragment with spherulites.

F: Slide No. A3, Horseshoe Canyon, parallel nicols, X25. Siltstone with parallel laminae of carbonaceous vegetal matter.

G: Slide No. RC/S35, Wizard Lake, parallel nicols, X25. Sandstone-siltstone contact.

H: Slide No. P4, Standard, parallel nicols, X25. Intraformational granule-conglomerate showing elongated fragments of siltstone in a sandy matrix.

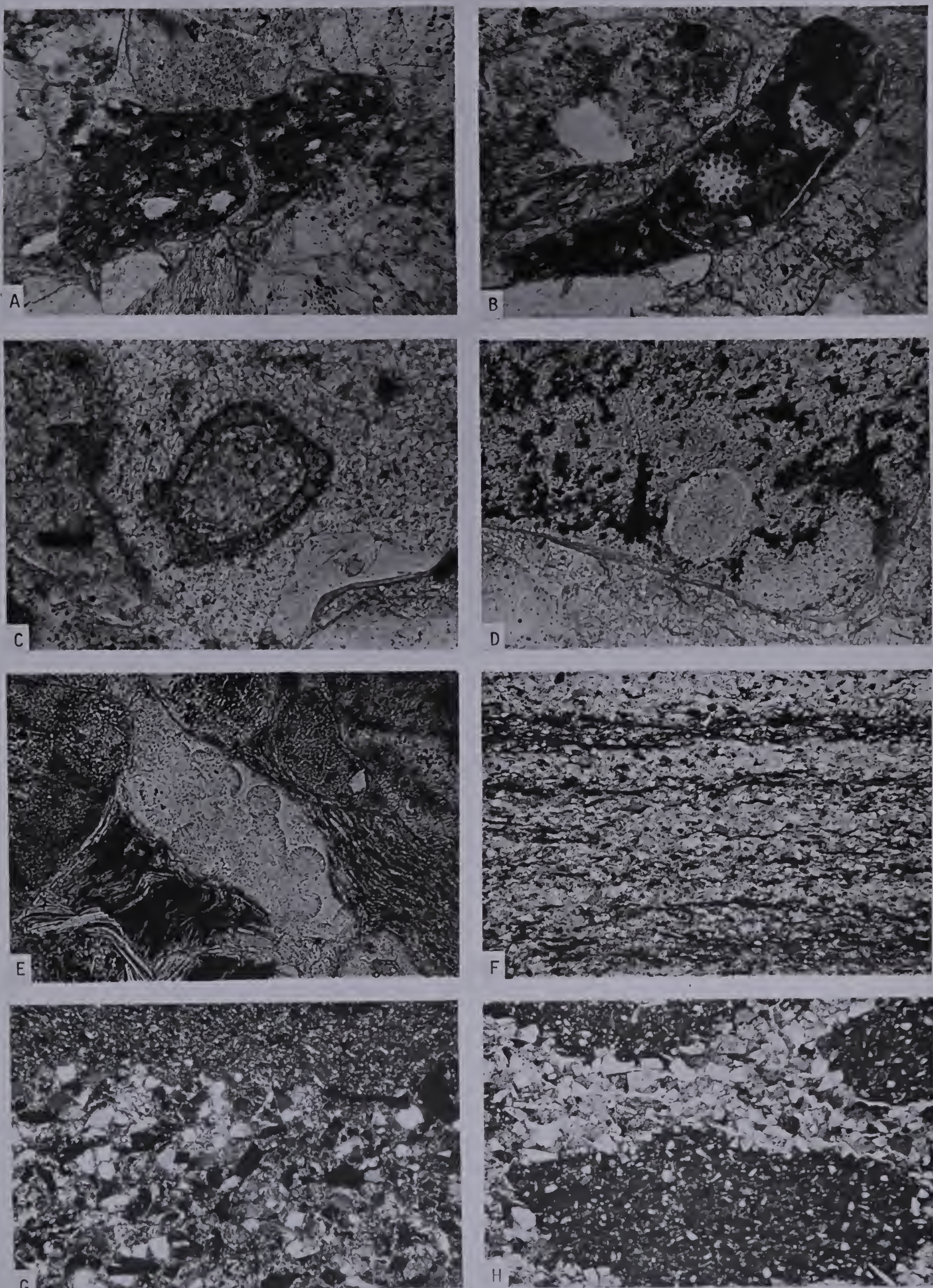


PLATE XX

EXPLANATION OF PLATE XXI

Siderite and vegetal macrofossils of the Whitemud Formation

A: Slide No. H11, Eastend, Sask., parallel nicols, X60. Photomicrograph of spherosiderite.

B: Slide No. H16, Eastend, Sask., crossed nicols, X60. Photomicrograph of siderite spherulite in clay matrix.

C and D: Slide No. H16, Eastend, Sask.; C: parallel nicols; D: crossed nicols; X160. Photomicrographs of siderite spherulites.

E: Slide No. RC/S40, Wizard Lake, parallel nicols, X160. Photomicrograph of authigenic siderite associated with biotite.

F and G: Vegetal macrofossils of the Whitemud Formation.

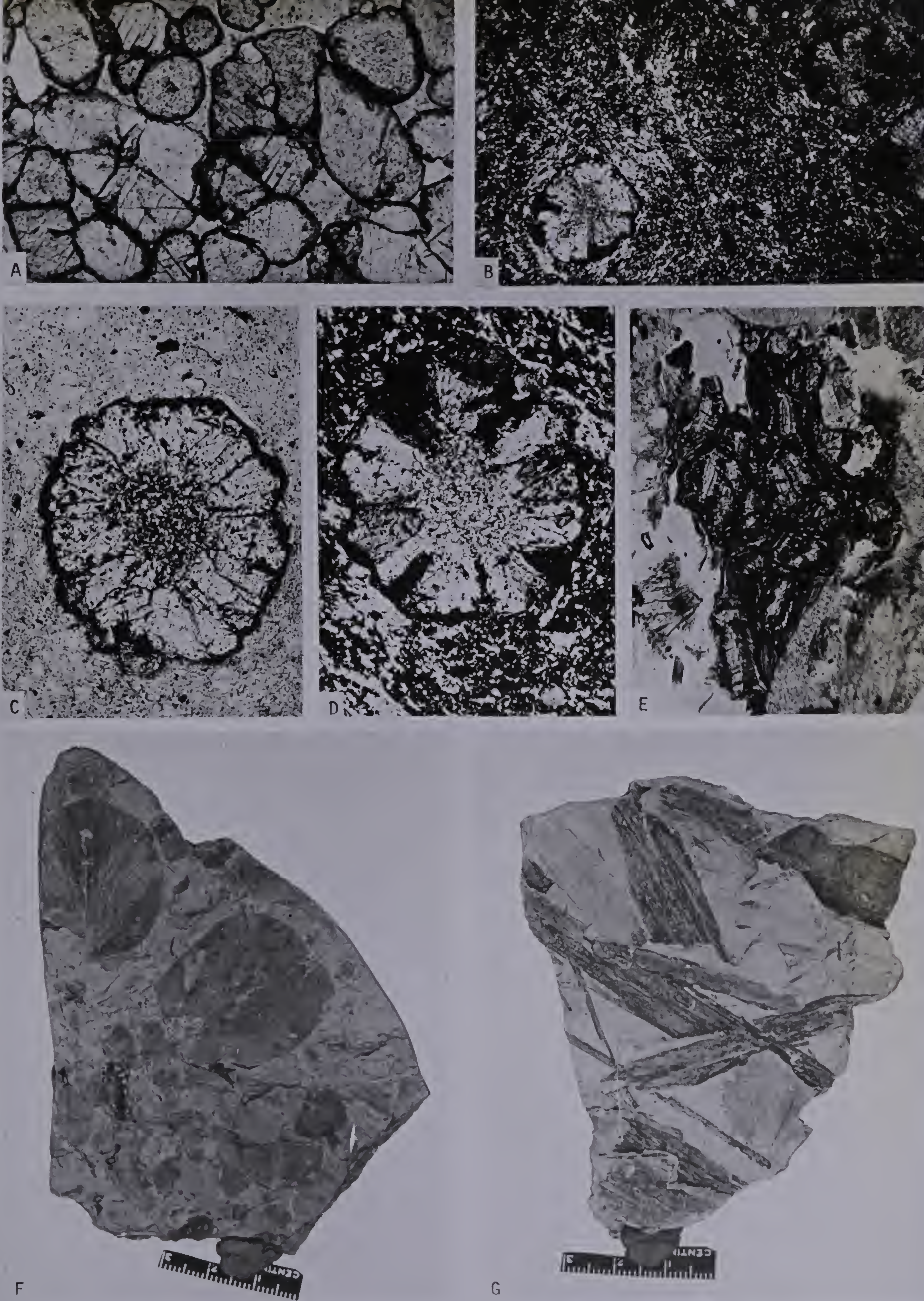


PLATE XXI

APPENDIX A

MEASURED SECTIONS

Section A. Locality: Horseshoe Canyon - NE corner of Sec. 27,
Twp. 28, Rg. 21, W4.

Thickness
(meters) (Sample numbers in brackets)

2.00 -- Clay, yellowish, weathered and mostly covered. Glacial pebbles on top.

0.25 -- Tuff, hard, siliceous, light grey, ledge-forming, weathered surface fracturing in angular fragments. Vacuoles up to 1.5 cm in diameter, empty or filled with light brown clay or opaline silica (A-TUFF).

11.20 -- Claystone, blocky, brown grey, weathering in typical "frothy" mauve-brown surface. One 5 cm thick hard tuffaceous bed (A31) present at m 2.20 below contact with major tuff bed (A33-A22).

0.40 -- Sandstone, fine, silty, bentonitic, light olive grey, lighter on the weathered surface. Leaching of overlying clay forms dark vertical streaks in the light colored sandstone (A21).

0.62 -- Claystone, brown grey, blocky, same as A33-A22 (A20).

2.53 -- Sandstone, fine, silty, bentonitic, light grey to almost white on weathered surface (A19-A17).

0.28 -- Coal, lignitic, greyish black, thinly layered, unidentifiable plant remains visible. Small specks of sulphur (A16).

0.96 -- Claystone, silty, olive grey, weathering yellowish grey (A15, A14).

0.34 -- Sandstone, very fine, silty, light grey, weathering yellowish grey, laminated (A13).

0.98 -- Shale, silty, light brown, fissile, elongated vegetal fragments visible (A12, A11).

0.25 -- Shale, carbonaceous, silty, greyish brown, fissile, carbonaceous vegetal remains visible (A10).

0.76 -- Shale, silty, light olive grey, fissile (A9).

0.40 -- Shale, silty, greenish grey, laminated with bands 2 to 20 mm thick of silty sandstone (A8).

Section A (continued...)

Thickness
(meters)

0.32 -- Sandstone, very fine, silty, light grey (A7).

0.85 -- Shale, pale olive, laminated (A6).

0.14 -- Siltstone, greenish grey, weathering yellow, laminated with some convolutions (A5).

0.53 -- Shale, silty, greyish brown, fissile, carbonaceous imprints (A4).

1.05 -- Siltstone, greenish grey, laminated with varve-like structures (A3, A3-2).

0.25 -- Sandstone, very fine, silty, light grey weathering yellowish grey, small scale cross-bedding, brown, cylindrical rods 3 mm in diameter perpendicular to stratification (A2).

0.15 -- Shale, silty, greenish grey, weathering yellowish grey, spherical iron concretionary bodies 3-4 mm in diameter present in the shale, elongated dark streaks of vegetal matter visible (A1).

Section B. Locality: Horseshoe Canyon - NE corner of Sec. 34,
Twp. 28, Rg. 21, W4.

Thickness
(meters) (Sample numbers in brackets)

1.00 -- Sandy clay with glacial pebbles.

3.00 -- Claystone, mauve-brown weathering surface. No fresh material available.

0.25 -- Tuff, light grey, hard, siliceous, vacuolar (B9).

4.10 -- Claystone, dark grey to brown grey at top, light grey at bottom, typical mauve brown "frothy" weathering surface (B8-B4). 20 cm of light grey fine grained sandstone approximately 2 m below contact with tuff (B5a).

1.25 -- Sandstone, fine, silty, yellowish grey (B3-B1).

0.15 -- Coal, lignitic.

Section D. Locality: Big Valley - SE corner of Sec. 16,
Twp. 35, Rg. 20, W4.

Thickness
(meters) (Sample numbers in brackets)

-- Vegetal cover.

3.00 -- Claystone, brown grey, blocky, weathering in a typical "frothy" mauve-brown surface (D15).

1.90 -- Shale, silty, light grey to yellowish grey, fissile (D14, D13).

0.76 -- Sandstone, fine, bentonitic, light grey to yellowish grey, almost white on weathered surface, showing 1-2 cm large flakes of light grey shale (D12, D11).

1.05 -- Shale, light olive grey, scaly (D10, D9).

0.55 -- Shale, silty, dark grey to brown grey, fissile (D8).

0.80 -- Sandstone, very fine to siltstone, bentonitic, light olive grey to yellowish grey. Vertical rods of dark clay cut across stratification, probably leached from above (D7).

0.58 -- Shale, light olive grey, reddish brown on weathered surface, scaly (D6).

0.75 -- Siltstone, light grey, fissile (D5).

1.45 -- Shale, light olive grey, scaly (D4-D3).

1.20 -- Sandstone, very fine to siltstone at top, fine at bottom, light greenish grey (D2, D1).

0.40 -- Shale, carbonaceous, black to dark grey, fissile to scaly (D0).

Section E. Locality: Scollard - NW corner of Sec. 15,
Twp. 34, Rg. 21, W4.

Thickness (meters) (Sample numbers in brackets)

-- Vegetal cover.

3.10 -- Sandstone, coarse to medium, yellowish grey to buff, cross-bedded (E24-E22).

2.00 -- Claystone, silty, blocky, olive grey (E21, E20).

1.20 -- Siltstone, olive grey, weathering yellowish red (E19).

2.00 -- Sandstone, fine, light green grey; 10 cm thick bands of dark red iron concretions, mostly siderite (E18), occurring at top, mid and bottom of sandstone (E17).

0.30 -- Claystone, yellowish grey.

0.20 -- Tuff, light grey, hard, siliceous, vacuolar, breaks down in angular fragments (E16a, E16b).

4.80 -- Claystone, blocky, brown grey, weathering in typical "frothy" mauve-brown surface (E15-E13).

0.70 -- Claystone, silty, light brown to yellowish grey with darker specks and mottling (E10).

6.20 -- Sandstone, fine, bentonitic, light greenish grey, weathering to very light grey. Very altered samples (E9-E4).

0.30 -- Shale, light olive grey, scaly (E3).

0.35 -- Shale, silty, medium grey to brownish grey, fissile. Vegetal fragments and coaly streaks visible (E2).

Siltstone, sandy, light grey, laminated (E1).

Sections F and G. Locality: Gleichen - NW corner of Sec. 13, Twp. 22, Rg. 23, W4.

Thickness
(meters) (Sample numbers in brackets)

-- Vegetal cover with some yellowish-grey claystone showing at places.

3.80 -- Claystone, brown grey, blocky, weathering in typical "frothy" mauve-brown surface (G14-G11).

0.14 -- Bentonite, light grey, fissile, white specks (G x 5).

0.18 -- Bentonite, brown grey to medium grey (G x 4).

0.12 -- Bentonite, tuffaceous, hard, light grey, vacuolar (G x 3).

0.10 -- Claystone, brown, unctuous, bentonitic (G x 2).

0.17 -- Tuff, medium grey, hard, siliceous (G10).

6.35 -- Claystone, blocky, brown grey to grey, weathering in typical "frothy" mauve-brown surface (G9-G3).

0.30 -- Shale, light olive grey, fissile (F5).

2.75 -- Claystone, light olive grey to light yellowish grey (F4-F1).

Base of the outcrop.

Section H. Locality: Eastend - Sec. 6, Twp. 7, Rg. 21, W3.

Thickness
(meters) (sample numbers in brackets)

0.65 -- Lignitic coal with brown claystone intercalations (H10-H8).

0.30 -- Claystone, yellow (H7).

1.00 -- COVERED interval.

3.30 -- Claystone, blocky, brown grey, weathering mauve brown, with typical "frothy" weathering surface. Thin beds of light grey bentonitic clay present in places (H6-H2).

0.50 -- Claystone, light grey, bentonitic (H1).

0.20 -- Spherosiderite, yellowish brown (H11).

1.00 -- Claystone, very light grey (H12).

1.10 -- Claystone, medium grey (H13).

2.90 -- Claystone, light greenish grey with horizontal laminae that look like varves (H14-H17).

0.80 -- Claystone, silty, light grey (H18).

2.50 -- Claystone, light brown, iron rich bands frequent (H19 and H20 only the upper meter).

1.00 -- Claystone, olive green (H21 and H23).

0.20 -- Lignitic coal, lensy (H22 and H24).

0.80 -- Claystone, blocky, dark gray (H25 and H26).

0.80 -- Sandstone, clayey, light grey, elongate "rod-like" vegetal remains cutting across, mostly perpendicular to bedding but also at random (H27). Toward the bottom this unit includes a 12 cm thick layer of laminated grey clay rich in vegetal remains.

0.90 -- Claystone, light brown to grey (H29-H30). One 5 cm thick layer of claystone at 35 cm from top is very rich in leaves (H29bis) and another one at the bottom is also rich in vegetal remains (H31).

Section H (continued...)

Thickness
(meters)

0.26 -- Coal (H32).

3.00 -- Sandstone, light brown to very light grey. Iron stained in places. Not indurated (H33-H36).

COVERED.

Section M. Locality: Scollard - SE corner of Sec. 18, Two. 34, Rg. 21, W4.

Thickness (meters)	(sample numbers in brackets)
	Sandstone, medium, "salt and pepper", weathering buff (M32).
0.70 --	Claystone, brown grey, unctuous (M31). It embeds a 5-7 cm lense of tuffaceous, hard, light grey bentonite (M33).
1.20 --	Claystone, light olive grey, with clusters and veinlets of dark brown montmorillonitic clay (M30).
2.45 --	Siltstone to very fine sandstone, light greenish grey to yellowish grey, weathering reddish brown (M29-M27).
0.20 --	Breccia of light greenish grey mud galls in a light grey silty matrix.
0.25 --	Claystone, brown grey, weathering mauve-brown (M25).
0.18 --	Tuff, hard, siliceous, medium grey, weathering in light grey angular fragments vacuolar (M24).
9.05 --	Claystone, blocky brown grey, weathering in typical "frothy" mauve-brown surface. Uppermost two meters somewhat lighter in color and with one 5-7 cm bed of hard, tuffaceous grey bentonite. Lower part also becoming lighter and gradational to underlying unit (M23-M14).
5.35 --	Claystone, more or less silty, but otherwise uniform throughout the interval, light grey to light brown, weathering yellowish brown (M13-M9).
0.15 --	Shale, dark brown, very coaly (M8).
1.30 --	Claystone, silty, light brown (M7, M6).
1.70 --	Shale, silty, brown grey with minute vegetal fragments and carbonaceous specks visible (M5, M4).
2.15 --	Siltstone, light to medium grey, laminated (M3-M1).
4.10 --	Sandstone, medium to fine, light grey, some beds form iron-sand concretionary bodies.
0.17 --	Coal, lignitic.
0.25 --	Shale, lignitic, reddish brown.

Section M (continued...)

Thickness
(meters)

0.85 -- Claystone, silty, medium grey.

1.60 -- Sandstone, medium, bentonitic, light greenish grey. Lentils of coal embedded.

0.25 -- Sandstone, yellow grey, iron cemented. Purple-red sideritic bed 5 cm thick at bottom.

1.85 -- Siltstone, medium grey, laminated. Frequent bands of reddish ironstone 2-5 cm thick.

Section N. Locality: Huxley - SW corner of Sec. 33,
Twp. 34, Rg. 21, W4.

Thickness
(meters) (Sample numbers in brackets)

Sandstone, coarse, "salt and pepper", weathering reddish yellow, frequent iron concretions (N21, N16A).

3.60 -- Claystone, light olive grey (N18, N17, N15).

0.55 -- Claystone, blocky, brown grey, weathering mauve brown (N13). It includes a 10-15 cm thick bed of light grey, hard tuffaceous bentonite (N14).

0.22 -- Tuff, hard, siliceous, medium grey, weathering light grey in angular fragments, vacuoles frequent, filled with light brown clay (N12).

3.20 -- Claystone, blocky, brown grey, weathering in typical "frothy" mauve-brown surface (N13-N8).

1.30 -- Siltstone to very fine sandstone, bentonitic, light grey, weathering almost white (N7, N6).

3.60 -- Sandstone, medium to fine, bentonitic, very light grey (N5-N2). It includes at the top a 15 cm thick bed of sandstone laminated with thin layers of vegetal remains (N5A), and, near the base, a 1-2 cm thick bed of lignitic coal (N2A).

0.35 -- Coal, lignitic (N1).

6.30 -- Interbedded sandstones, siltstones and shales with minor amounts of lignitic coals.

0.55 -- Coal, lignitic.

Section P. Locality: Standard -- NE corner of Sec. 30,
Twp. 24, Rg. 22

Thickness
(meters) (Sample numbers in brackets)

Soil with glacial pebbles.

6.75 -- Claystone, blocky, brown grey, weathering in typical "frothy" mauve-brown surface (P13-P7).

0.70 -- Claystone, silty, light grey with inclusions of dark grey montmorillonitic clay (P6).

0.30 -- Siltstone, light grey, weathering almost white, thinly bedded, inclusions of dark grey montmorillonitic clay in form of vertical rods 2 x 50 mm (P5).

0.75 -- Siltstone, light grey, weathering yellowish grey, with embedded fragments of pale olive claystone to give the aspect of a breccia (P4).

0.26 -- Sandstone, very fine to siltstone, light olive grey (P3).

0.38 -- Shale, pale olive (P2).

0.60 -- Shale, medium to dark grey, small carbonaceous fragments visible (P1).

Base of outcrop.

Section Q. Locality: Standard - NE corner of Sec. 20,
Twp. 24, Rg. 22, W4.

Thickness
(meters) (Sample numbers in brackets)

Covered interval.

0.30 -- Tuff, hard, siliceous, medium grey, vacuolar, thinly bedded (Q16).

4.80 -- Claystone, blocky, brown grey, weathering in typical "frothy" mauve-brown surface (Q15-Q11).

1.55 -- Claystone, very light brown, weathering almost white (Q10-Q8).

1.90 -- Shale, silty, light olive grey, weathering yellowish grey (Q7-Q5).

1.15 -- Shale, brown grey, imprints and fragments of vegetal matter visible (Q4, Q3).

0.20 -- Sandstone, fine to very fine, light grey, weathering yellowish grey (Q2).

0.60 -- Siltstone to very fine sandstone, light olive grey, weathering yellowish grey, laminated and with very small cross-bedding (Q1) alternating with 3 cm thick beds of shale, light olive grey (Q1A).

Base of outcrop.

Section S. Locality: Elkwater, Quarry 45 - NE corner of Sec. 9, Twp. 8, Rg. 4, W4.

Thickness (meters) (Sample numbers in brackets)

6.00 -- Sandstone, medium to coarse, grey on fresh surface, "salt and pepper" to reddish yellow upon weathering (S1).

0.20 -- Iron-concretionary bed in clay-silt matrix, orange-yellow.

2.60 -- Claystone, blocky brown grey, weathering in typical "frothy" mauve-brown surface. Large crystals of secondary quartz embedded (S3-S5).

0.30 -- Bentonite, light grey (S6).

0.25 -- Tuff, hard, siliceous, light grey, with vacuoles filled with opaline silica or montmorillonite. It weathers in angular fragments (S-TUFF).

5.90 -- Claystone, blocky, brown grey, weathering mauve-brown. (SS1-SS4, SS6, S7, S10-S13). In the upper two meters is present a 10 cm thick layer of hard, medium grey tuff, very similar to the one described above but less vacuolar and with some thin parallel partition or fissility (SS5). This interval also includes at about three meters from the top, a bed of varved clay and graded conglomerate of glacial origin, probably deposited by a sort of crevasse-filling mechanism (S8, S9).

1.10 -- Claystone, blocky, medium grey to light brownish grey, with minute dark specks and carbonaceous vegetal fragments (S14, S15).

1.55 -- Sandstone, very fine to siltstone, kaolinitic, very light grey to white, small muscovite flakes visible (S16-S18).

0.26 -- Claystone, silty, very light brown (S19).

0.19 -- Claystone, kaolinitic, creamy white, subconchoidal fracture (S20).

0.60 -- Claystone, blocky, brown grey, weathering reddish brown (S21).

0.68 -- Claystone, silty, creamy white (S22).

0.58 -- Claystone, kaolinitic, very light bluish grey weathering to white, laminated with varve-type structure (S23).

Section S (continued...)

Thickness
(meters)

0.25 -- Siltstone, kaolinitic, light grey (S24).

0.55 -- Claystone, kaolinitic, very light bluish grey, laminated as above (S25).

0.15 -- Shale, carbonaceous, dark grey to black, coaly vegetal fragments and lignitic coal partings (S26).

0.44 -- Claystone, blocky, light brown grey (S27).

0.56 -- Claystone, silty, light olive grey, specks and cylindrical rods of darker clay without preferred orientation (S28, S29).

0.40 -- Claystone, very light olive grey, subconchoidal fracture, large inclusions of dark montmorillonitic clay (S30).

2.15 -- Sandstone, fine, to siltstone toward the base, light grey (S31-S33).

2.50 -- Claystone, light grey, laminated with silty units in places. Beds of leaves (compare to genus Typha) are present in very thin units or in 2 cm thick beds (S36). Vertical carbonaceous rods, probably roots, cut across the stratification (S34-S38).

Lowermost part of section not exposed.

Section U. Locality: Nevis Bridge - Sec. 5, Twp. 39, Rg. 22, W4.

Thickness (meters) (Sample numbers in brackets)

3.00 -- Claystone, blocky, brown grey to medium grey, weathering in typical "frothy" mauve-brown surface (U33-U31).

0.22 -- Tuff, hard, siliceous, light grey, vacuolar (U30).

10.70 -- Claystone, blocky, brown grey, medium to light grey, weathering as above (U29-U19).

0.40 -- Claystone, silty, blocky, light olive grey with lustrous, dark clay streaks 1-4 mm wide and up to 20 mm long cutting in all directions (U17).

0.15 -- Shale, slightly fissile, greenish grey (U16).

1.70 -- Shale, carbonaceous, dark brown to light brown, elongated vegetal fragments visible (U15, U14). Laterally it includes a 30 cm. thick lense of lignitic coal (U18).

0.90 -- Sandstone, very fine, silty, bentonitic, light greenish grey crossed in all directions by streaks of dark carbonaceous clay (U13, U12).

2.70 -- Sandstone, medium to fine, bentonitic, light grey, mud galls up to 20 mm in diameter embedded in the sandstone (U11-U9). Bands of laminated fine sandstone and organic matter (U10-11) present at about 1 m from top.

0.70 -- Coal, lignitic (U8).

1.10 -- Shale, silty, brownish grey, carbonaceous vegetal fragments and small streaks 2 mm wide, 15 mm long (U7).

1.24 -- Sandstone, very fine to siltstone, bentonitic, laminated, light greenish grey (U6, U5). 10 cm thick lentils of dark grey shale intercalated (U4).

0.55 -- Shale, silty, medium grey (U3).

0.68 -- Shale, silty, pale olive grey (U2).

0.80 -- Coal lignitic (U1).

Section W. Locality: Wood Lake - SW corner of Sec. 3, Twp. 38, Rg. 22, W4.

Thickness (meters)	(Sample numbers in brackets)
5.00 --	Claystone, weathered surface mauve-brown. Impossible to obtain fresh samples. Fragments of light grey, hard, siliceous tuff found in rubble.
0.40 --	Claystone, silty, light olive grey (W14).
1.90 --	Sandstone, very fine to siltstone, bentonitic, very light grey, weathering to almost white (W13, W12).
1.10 --	Siltstone, bentonitic, fissile, light grey (W11).
0.35 --	Shale, medium to light grey (W10).
1.00 --	Shale, carbonaceous dark grey to black, alternating with small beds of lignitic coal and showing specks of sulphur (W9).
0.30 --	Siltstone, light olive grey (W8).
7.50 --	Sandstone, fine to medium, bentonitic weathering, very light grey to almost white (W7-W1).

Section Y. Locality: Ardley - NE corner of Sec. 34, Twp. 38, Rg. 23, W4.

Thickness (meters) (Sample numbers in brackets)

Approximately
12.00 -- Covered interval, recessive with mauve-brown weathering claystone appearing at places. Only one sample collected at the base (Y14).

1.20 -- Claystone, silty, light grey to almost white, with mottling and specks of a darker grey clay (Y13).

8.90 -- Sandstone, fine at top, medium to coarse at bottom, friable, light greenish grey, weathering almost white (Y11-Y3).

0.05 -- Sandstone, medium, well cemented, brown grey, weathering reddish brown (Y2).

0.30 -- Coal, lignitic (Y1).

Section α. Locality: Red Deer River, between Munsen and Morrin - Sect. 32, Twp. 30, Rg. 21, W4.

Thickness (meters) (Sample numbers in brackets)

Vegetal cover.

0.60 -- Sandstone, medium, very friable, "salt and pepper" (α31).

0.57 -- Shale, light olive grey, weathering yellow grey (α30).

0.18 -- Sandstone, medium-fine, very friable, "salt and pepper" (α29).

0.16 -- Coal, lignitic (α28).

0.12 -- Sandstone, very fine, to siltstone, pale olive (α27).

0.10 -- Claystone, blocky, light greenish grey, weathering reddish yellow (α26).

0.10 -- Claystone, silty, blocky, light grey (α25).

0.20 -- Claystone, blocky, brown grey.

0.35 -- Sandstone, medium, very friable, olive grey, buff on weathered surface (α24).

0.35 -- Tuff, hard, siliceous, light grey to medium grey, weathering in angular fragments, vacuoles filled with light brown bentonitic clay (α1-α3).

6.40 -- Covered interval with some very weathered brown grey claystone of typical Battle facies showing in several points. Only one sample collected (α23), at contact with underlying unit.

0.45 -- Shale, silty, light grey (α22).

1.05 -- Sandstone, medium, bentonitic, light grey (α20).

1.00 -- Sandstone, very fine to siltstone, bentonitic, light grey (α18).

0.50 -- Shale, light olive brown (α17).

2.00 -- Sandstone, medium, bentonitic, light greenish grey, weathering to yellowish grey (α16-α14).

0.65 -- Shale, silty, medium to light grey (α13).

0.30 -- Claystone, olive brown (α12).

Section α (continued...)

Thickness
(meters)

1.15 -- Coal, lignitic, alternating with light brown blocky claystone (α11).

4.50 -- Sandstone, medium to fine, bentonitic, light grey, weathering yellowish grey (α10-α7).

0.12 -- Siltstone, carbonaceous, alternating with laminae of coaly vegetal matter (α6).

1.55 -- Sandstone, medium to fine, bentonitic, light grey (α5, α4).

Section β. Locality: Wood Lake - SE corner of Sec. 23,
Twp. 37, Rg. 22, W4.

Thickness (meters)	(Sample numbers in brackets)
5.00	-- Covered, recessive with yellowish grey claystone showing at places. Impossible to obtain fresh samples.
1.00	-- Claystone, bentonitic, light grey (β35).
2.20	-- Claystone, blocky, medium grey to brown grey, weathering mauve-brown (β34, β33).
0.25	-- Tuff, hard, siliceous, medium grey weathering light grey, vacuolar (β32).
7.00	-- Claystone, blocky, brown grey, weathering in typical "frothy" mauve-brown surface (β31-β25).
1.40	-- Shale, silty, light brown (β24-β23).
1.20	-- Shale, light bluish grey (β22-β19).
1.00	-- Shale, silty, light brown, laminated with 1-2 mm thick beds of vegetal matter (β18).
0.40	-- Shale, dark grey (β17).
0.90	-- Shale, dark brown, weathering in light reddish brown (β16).
0.30	-- Siltstone, bentonitic, light grey, weathering yellowish grey (β15).
0.80	-- Shale, silty, light brown, elongated vegetal remains 1 x 3-4 mm visible (β14).
0.75	-- Shale, light grey, scaly (β13).
1.90	-- Siltstone to very fine sandstone, light grey to yellowish grey, laminated with carbonaceous laminae up to 4 mm thick (average 2 mm) unevenly spaced (β12, β11).
1.50	-- Shale, light to medium grey (β10, β9).
0.60	-- Sandstone, very fine, bentonitic, patches and streaks of dark montmorillonitic clay (β8).
0.55	-- Shale, brown grey with small carbonaceous specks (β7).

Section β (continued...)

Thickness
(meters)

5.90 -- Shale, silty at spots, but mostly clayey, light to medium grey, weathering yellowish grey (β6-β3).

2.10 -- Sandstone, fine, light grey, weathering yellowish grey (β2).

Base of outcrop -- Shale, dark grey to black (β1).

Section WL (R.C.A. No. 65-1 core). Locality: Wizard Lake - Sec. 8, Twp. 48, Rg. 27, W4.

Thickness (meters) (Sample numbers in brackets)

Sandstone, medium to fine, silty, light grey.

1.05 -- Claystone, light grey, slightly fissile (WL48-WL46).

1.00 -- Claystone, blocky, brown grey (WL45-WL43).

0.20 -- Tuff, hard, siliceous, light to medium grey (WL42, WL41).

4.10 -- Claystone, blocky, brown grey (WL40-WL31). (RCS V2-RCS V5).

0.30 -- Claystone, silty, yellow grey with embedded "galls" or fragments of the dark claystone above (WL30).

1.40 -- Siltstone to very fine sandstone, yellow grey (WL29, WL28).

18.10 -- Sandstone, generally medium to fine grained, but some beds coarse to medium, light grey to olive grey, usually bentonitic and friable. Two layers of respectively 75 and 40 cm. Well cemented ($CaCO_3$ cement). (WL27-WL10) (RCS35-RCS44).

0.25 -- Claystone, dark brown, carbonaceous inclusions (WL9).

0.75 -- Siltstone, yellow grey (WL8).

0.60 -- Claystone, yellow grey (WL7).

1.05 -- Siltstone, light grey, dark carbonaceous elongated imprints (WL6).

1.20 -- Claystone, silty, dark grey, vertical carbonaceous streaks (WL5).

0.25 -- Siltstone to sandstone, light grey with dark mottling.

0.80 -- Siltstone, dark grey to brown, apparently massive, yellow bentonite pebbles or galls (WL4).

1.00 -- Sandstone, very fine to siltstone, dark grey, clay laminae visible (WL3).

0.60 -- Sandstone, very fine to siltstone, light greenish grey (WL1).

4.80 -- Claystone, and siltstone, olive grey, siltstone frequently shows bands of organic matter (RCS49-RCS52).

0.70 -- Coal.

APPENDIX B

GRAIN-SIZE DISTRIBUTION TABLES

AND GRAPHS (IN POCKET)

TABLE XII

Clay and Silt Content of Sandstones of the Edmonton Formation

Sample No.	Percentage of fines (minus 62.5 μ)	Sample No.	Percentage of fines (minus 62.5 μ)
A17	34	W3	25
A18	39	W4	28
A19	30	W5	27
B1	33	W6	32
B2	34	W7	32
B3	27	W13	35
D1	36	Y3	17
D2	50	Y4	23
D7	40	Y6	21
E5	31	Y7	31
E7	47	Y8	30
E8	53	WL10	17
E22	13	WL11	14
E23	17	WL12	17
E24	20	WL13	13
H34	16	WL14	11
H35	12	WL15	14
H36	12	WL16	12
J1	45	WL17	8
J2	39	WL18	13
L3	18	WL19	26
L4	21	WL20	19
L5	20	WL21	22
L7	26	WL22	20
N2	32	WL23	25
N3	37	WL24	17
N4	40	WL25	27
N5	36	WL26	36
U4	35	WL27	27
U5	47	α4	28
U9	30	α5	30
U10	34	α7	26
U11	36	α8	34
V1	29	α9	38
V2	28	α10	39
V3	31	α14	27
V4	44	α15	26
V5	47	α16	32
W1	23	α18	27
W2	22	α20	23

TABLE XIII

GRAIN-SIZE FREQUENCY DISTRIBUTION OF THE SAND FRACTIONS

Sample No.	Percentages in each class (quarter Phi)(1)																
	-.25 -0	0- .25	.25- .50	.50- .75	.75- 1.00	1.00- 1.25	1.25- 1.50	1.50- 1.75	1.75- 2.00	2.00- 2.25	2.25- 2.50	2.50- 2.75	2.75- 3.00	3.00- 3.25	3.25- 3.50	3.50- 3.75	3.75- 4.00
WL10	0	0	0.32	1.16	2.85	12.64	16.86	17.60	14.96	11.48	8.03	4.54	3.38	2.32	1.99	1.16	0.74
WL11	0.21	0.11	0.74	2.85	8.66	18.69	17.00	14.57	11.51	8.98	5.81	3.59	2.53	1.79	1.16	1.06	0.74
WL12	0	0.21	0.21	0.42	1.17	7.42	17.29	20.79	17.07	12.51	7.53	5.09	3.82	2.86	1.91	1.17	0.53
WL13	0	0.11	0	0.32	1.81	12.11	21.89	18.49	14.56	10.63	7.01	4.68	2.87	2.02	1.49	1.27	0.74
WL14	0	0.22	0.78	1.66	5.88	20.40	23.06	15.08	8.76	6.10	5.65	4.32	2.99	2.11	1.55	1.11	0.33
WL15	0	0	0	0.64	2.34	12.79	21.75	19.94	14.39	9.38	6.72	4.16	2.66	2.34	1.17	0.96	0.75
WL16	0	0	0	0.21	1.17	16.15	29.44	17.75	10.20	6.80	5.31	4.46	3.08	2.12	1.27	0.96	1.06
WL17	0	0	0.21	0.62	4.32	25.31	26.65	16.15	8.23	5.35	4.01	2.47	1.95	1.13	2.37	0.72	0.51
WL18	0	0	0.22	0.43	1.09	2.17	4.46	13.04	12.93	16.02	13.55	9.67	7.50	6.20	5.65	4.46	4.18
WL19	0	0.11	0.11	0.11	0.21	0.43	1.82	2.36	2.14	6.11	12.00	18.86	21.01	14.79	9.65	6.11	4.18
WL20	0.42	0.11	0.11	0	0.11	0.11	0.11	0.85	7.29	25.37	22.73	17.86	10.46	5.50	4.12	3.07	1.80
WL21	0	0.11	0.32	0.53	0.21	0.53	0.32	0.53	2.23	21.70	20.74	19.04	13.51	8.08	4.89	4.04	3.19
WL22	0.21	0.21	0.11	0.21	0.32	0.21	0.32	1.38	16.67	30.26	19.53	11.04	6.79	4.46	3.82	2.65	1.80
WL23	0	0.32	0.11	0.11	0.11	0.21	0.63	1.27	6.56	21.90	19.36	17.57	12.49	7.83	4.87	3.81	2.86
WL24	0	0.10	0.10	0.10	0.21	1.05	15.17	22.28	19.77	13.60	8.58	5.96	4.29	3.14	3.14	1.57	0.94

(1) Percentages have been rounded to the second decimal figure, but the validity of the second decimal figure is not implied.

Sample No.	Percentages in each class (quarter Phi)																
	-.25- -0	0- .25	.25- .50	.50- .75	.75- 1.00	1.00- 1.25	1.25- 1.50	1.50- 1.75	1.75- 2.00	2.00- 2.25	2.25- 2.50	2.50- 2.75	2.75- 3.00	3.00- 3.25	3.25- 3.50	3.50- 3.75	3.75- 4.00
WL25	0	0	0.21	0.21	0.11	0.11	0.21	0.43	8.85	28.57	23.88	14.92	8.32	5.01	3.73	3.09	2.34
WL26	0	0	2.22	0	0.11	0	0	0	0.22	14.05	28.65	23.89	13.40	7.68	5.51	3.89	2.38
WL27	0.21	0	0	0.11	0	0.11	0.11	0.95	17.14	21.37	19.05	13.76	10.37	6.67	4.76	3.28	2.12
W1	0	0	0	0	0	0	0.78	5.04	26.46	26.34	16.93	8.30	5.27	3.92	2.80	2.47	1.68
W2	0	0	0	0	0	0.54	4.35	23.80	22.50	17.06	10.22	6.41	4.67	3.48	3.26	2.06	1.63
W3	0	0	0	0	0	0.32	0.65	11.13	26.16	21.19	15.68	7.89	5.62	4.43	3.35	1.30	2.27
W4	0	0	0	0	0	0.86	4.61	18.88	22.85	18.03	12.45	7.40	4.83	3.97	2.68	2.15	1.29
W5	0	0	0	0	0	0.21	0.85	11.28	28.30	21.49	12.77	8.51	5.53	4.04	3.08	2.34	1.60
W6	0	0	0	0	0	0.21	1.17	11.60	28.19	20.11	11.49	6.81	7.02	4.47	3.62	3.40	1.91
W7	0	0	0	0	0	0.11	0.11	0.43	1.60	15.72	19.89	21.39	17.00	9.73	6.63	4.38	2.99
W13	0	0	0	0	0	0	0.65	8.26	24.46	25.65	14.02	9.78	5.87	4.13	3.26	2.28	1.63
V1	0	0	0	0	0.86	2.35	24.06	24.06	15.08	9.73	6.74	5.13	3.96	2.89	2.03	1.92	1.18
V2	0	0	0	0.74	3.71	20.81	23.46	15.39	10.51	8.70	6.05	3.82	2.44	1.49	1.17	0.95	0.74
V3	0	0	0	0	0.54	1.94	21.03	19.31	16.72	13.16	8.41	5.93	4.31	3.24	2.37	1.83	1.19
V4	0	0.11	0	0.11	0	0.22	0.66	3.31	10.26	21.74	20.64	14.90	11.70	7.06	4.41	3.09	1.77
V5	0	0	0	0	0	0	0.57	0.80	1.82	10.69	22.98	22.07	16.04	10.58	7.17	4.44	2.84

Sample No.	Percentages in each class (quarter Phi)																
	-.25 -0	0- .25	.25- .50	.50- .75	.75- 1.00	1.00- 1.25	1.25- 1.50	1.50- 1.75	1.75- 2.00	2.00- 2.25	2.25- 2.50	2.50- 2.75	2.75- 3.00	3.00- 3.25	3.25- 3.50	3.50- 3.75	3.75- 4.00
D1	0	0	0	0	0	0	0	0	0.66	12.35	20.07	18.08	16.32	12.24	9.37	6.17	4.74
D2	0	0	0	0	0	0	0	0	0	1.08	11.31	10.11	15.64	16.61	17.21	16.37	11.67
D7	0	0	0	0	0	0	0	0.22	1.30	13.15	13.91	20.43	20.43	14.35	8.37	4.67	3.15
Y3	0	0.21	0.52	2.09	5.44	14.97	21.15	15.92	10.47	8.27	6.81	4.40	2.93	1.99	1.88	1.47	1.47
Y4	0	0	0	0	1.81	8.86	16.97	15.47	13.13	11.63	10.67	7.47	5.34	3.31	2.24	1.81	1.28
Y6	0	0	0	0	0	0	0.85	17.66	25.64	20.74	13.19	7.87	5.74	3.30	2.23	1.49	1.28
Y7	0	0	0	0	0	0	0.22	0.67	2.00	26.36	24.36	16.13	12.46	7.23	4.56	3.56	2.45
α4	0	0	0	0	0	0	1.39	19.08	27.29	20.26	12.05	7.46	4.37	3.20	2.03	1.71	1.17
α5	0	0	0	0	0	0.64	2.56	12.50	16.35	16.35	14.32	12.39	9.83	5.77	4.11	2.62	2.56
α7	0	0	0	0	0	0.42	3.88	21.30	18.05	14.48	13.01	9.44	7.13	4.51	3.25	3.15	1.36
α8	0	0	0	0	0	0	0.22	1.22	10.90	24.36	3.23	39.93	8.12	4.67	3.11	2.22	2.00
α9	0	0	0	0	0	0	0	0	0.67	13.73	23.21	23.86	15.07	9.17	6.58	4.46	3.24
α10	0	0	0	0	0	0	0	0	1.01	16.42	21.90	19.66	14.64	10.39	7.60	5.03	3.35
α14	0	0	0	0.11	0.86	3.77	18.75	21.77	15.84	11.75	7.76	5.39	4.42	3.02	2.37	2.26	1.94
α15	0	0	0	0	0	0.44	2.19	24.18	24.18	19.91	10.72	5.69	4.16	3.39	2.30	1.53	1.31
α16	0	0	0	0	0	0.21	0.64	2.80	18.06	23.44	20.97	12.15	7.20	5.05	3.98	3.33	2.15

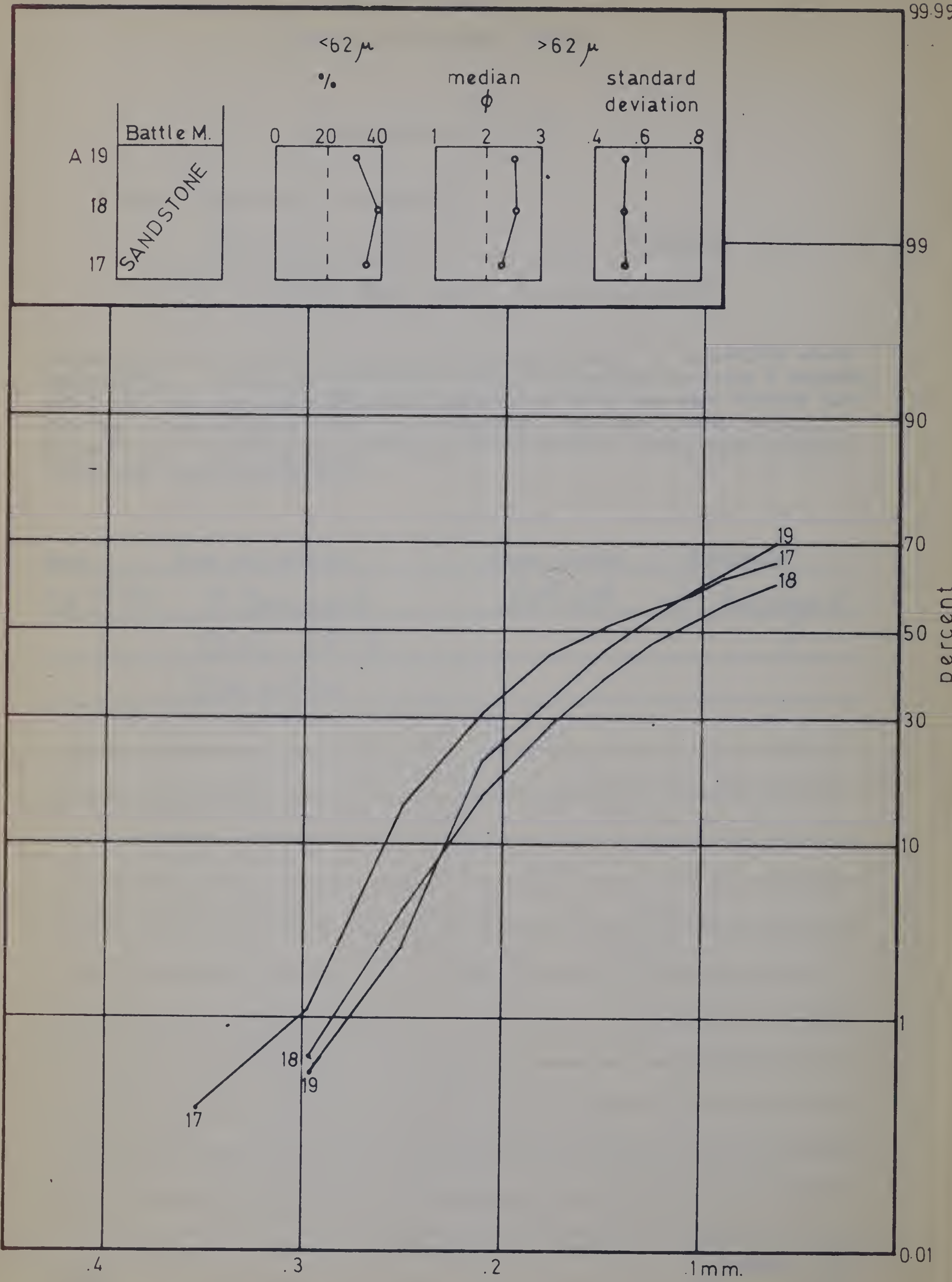
Sample No.	Percentages in each class (quarter Phi)																
	-.25 -0	0- .25	.25- .50	.50- .75	.75- 1.00	1.00- 1.25	1.25- 1.50	1.50- 1.75	1.75- 2.00	2.00- 2.25	2.25- 2.50	2.50- 2.75	2.75- 3.00	3.00- 3.25	3.25- 3.50	3.50- 3.75	3.75- 4.00
α18	0.21	0.11	0.21	0.21	0.42	1.80	16.86	24.71	20.78	11.88	6.57	4.24	3.29	3.07	2.23	2.01	1.38
α20	0	0	0	0.10	0.31	4.27	35.10	22.81	13.23	7.40	4.27	3.30	2.01	1.87	1.35	1.04	2.92
A17	0	0	0	0	0	0	0.31	1.46	20.54	24.82	20.02	10.53	6.36	5.11	5.84	3.02	1.98
A18	0	0	0	0	0	0	0	0.87	6.52	19.13	20.22	16.74	13.59	8.80	6.30	4.67	3.15
A19	0	0	0	0	0	0	0	0.57	3.52	26.59	17.95	16.36	11.82	7.50	6.25	5.11	4.32
E5	0	0	0	0	0	0	0	0.76	4.15	26.45	28.42	17.27	8.74	5.35	3.82	2.95	2.08
E7	0	0	0	0	0	0	0	0	1.21	18.24	22.09	24.61	14.40	8.13	5.60	3.52	2.20
E8	0	0	0	0	0	0	0	0	0.86	11.83	31.72	21.93	14.09	7.31	5.16	4.09	3.01
E22	0	0	0	0.11	0.88	4.07	20.22	20.88	16.04	12.75	8.79	6.26	3.63	2.53	1.65	1.21	0.99
E23(2)	0	0	0.22	0.33	1.10	4.74	24.23	18.06	13.22	10.46	7.93	5.51	4.51	3.41	2.53	1.98	1.76
E24	0	0	0	0	0	0.22	0.68	1.35	21.42	27.06	15.11	11.84	7.44	5.30	4.28	3.16	2.14
L3	0	0	0	0	0	0.11	1.81	21.57	28.48	19.13	11.58	5.74	3.93	2.76	2.34	1.38	1.17
L4	0	0	0	0	0	0	0.85	11.09	27.61	24.41	14.50	8.00	5.12	3.20	2.34	1.81	1.07
L5	0	0	0	0	0	0	0.85	13.40	28.94	21.81	13.94	8.30	5.32	3.19	2.13	1.06	1.06
L7	0	0	0	0	0	0	0.43	4.13	29.38	22.85	18.17	9.25	5.22	3.59	2.72	2.39	1.85
N2	0	0	0	0	0	0	0.11	0.79	16.74	30.56	19.55	10.00	6.97	5.17	4.04	3.37	2.70

(2) Not plotted because on rechecking it was found that the coarsest fraction was not completely disaggregated.

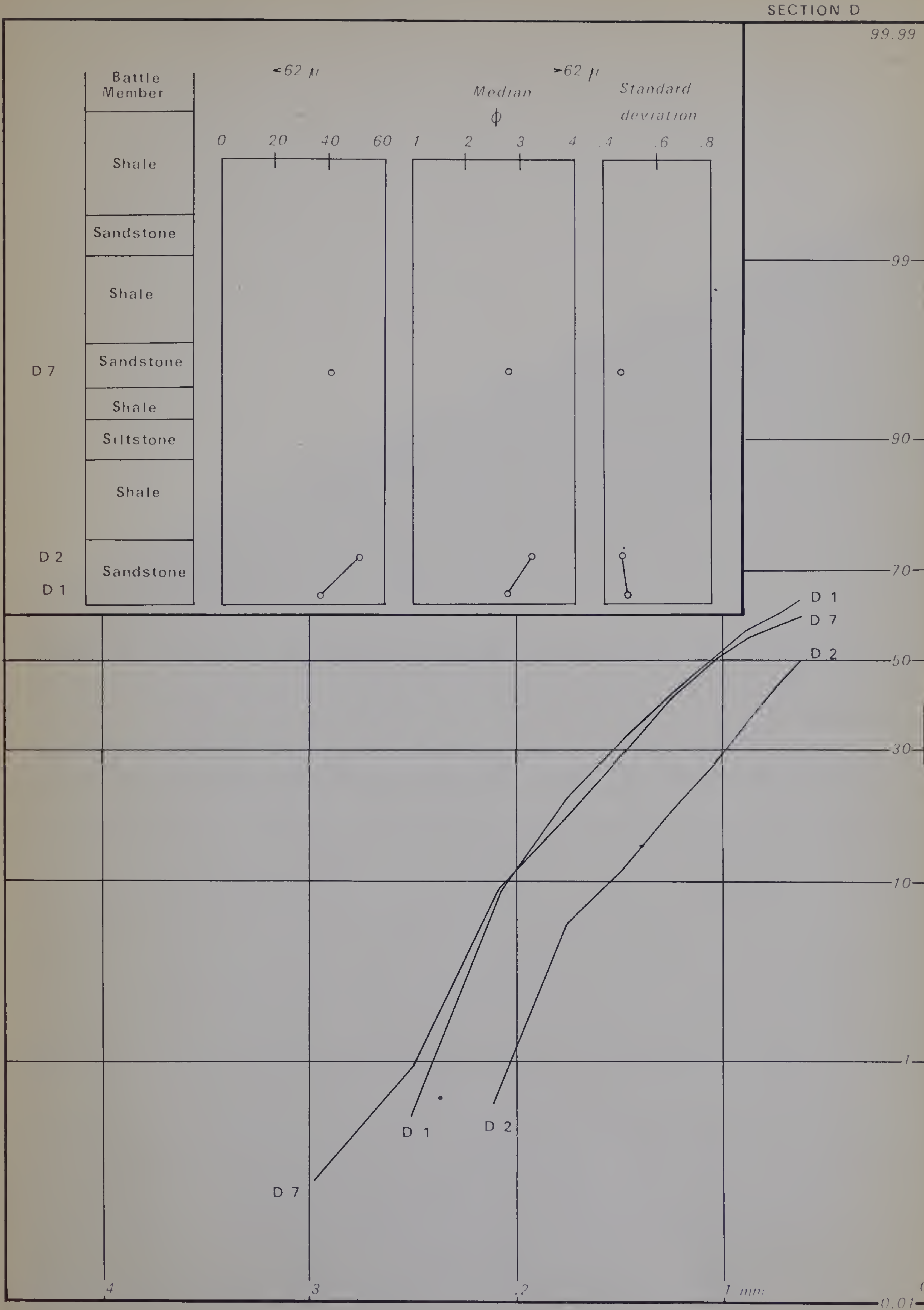
Sample No.	Percentages in each class (quarter Phi)																
	-.25 -0	0- .25	.25- .50	.50- .75	.75- 1.00	1.00- 1.25	1.25- 1.50	1.50- 1.75	1.75- 2.00	2.00- 2.25	2.25- 2.50	2.50- 2.75	2.75- 3.00	3.00- 3.25	3.25- 3.50	3.50- 3.75	3.75- 4.00
N3	0	0	0	0	0	0	0	0	0.34	15.71	25.46	24.77	13.07	8.26	5.62	4.36	2.41
N4	0	0	0	0	0	0	0	0	0.24	6.17	23.07	18.89	18.38	13.91	9.31	6.05	3.99
N5	0	0	0	0	0	0	0	0	1.99	32.28	25.35	14.08	8.92	5.99	4.58	3.99	2.82
U4	0	0	0	0	0	0	0	0	1.30	27.60	25.97	17.32	10.06	6.71	4.76	3.90	2.38
U5	0	0	0	0	0	0	0	0	0.34	2.84	13.64	14.32	1.25	27.16	17.50	13.86	9.09
U9	0	0	0	0	0	0	0.64	5.47	16.74	22.85	18.24	12.77	8.26	5.79	4.08	2.57	2.57
U10	0	0	0	0	0	0	0.32	7.32	33.09	24.81	14.00	7.42	4.88	3.29	2.23	1.70	0.95
U11(3)	0	0	0	0	0	0.43	0	0	1.07	28.11	24.68	18.67	11.16	6.33	4.40	3.00	2.15
J1(3)	0	0	0	0	0	0	0	0.77	2.43	16.26	14.71	15.38	17.26	11.06	9.73	7.30	5.09
J2(3)	0	0	0	0	0	0	0.42	5.20	27.47	21.42	14.85	10.07	7.74	4.98	3.71	3.07	1.06
H34(3)	0	0	0	0	0	0	0	0	4.32	26.90	27.95	19.41	9.60	4.64	3.16	2.11	1.90
H35(3)	0	0	0	0	0	0	0	0	0.42	8.54	22.47	31.75	21.83	7.17	3.69	2.32	1.79
H36(3)	0	0	0	0	0	0	0.10	0.21	0.10	3.90	19.62	29.33	24.26	11.18	5.70	3.59	2.00
B1(3)	0	0	0	0	0	0	0	0.32	3.36	34.78	24.27	15.17	7.80	5.20	4.12	2.60	2.38
B2(3)	0	0	0	0	0	0	0	0.54	10.42	29.31	26.93	13.68	7.27	4.13	3.26	2.39	2.06
B3(3)	0	0	0	0	0	0.21	1.59	25.80	29.30	18.79	9.13	5.20	3.29	2.23	2.23	1.17	1.06

(3) Not used in the factor analysis because of "lack of space" in the computer.

GRAPH I section A

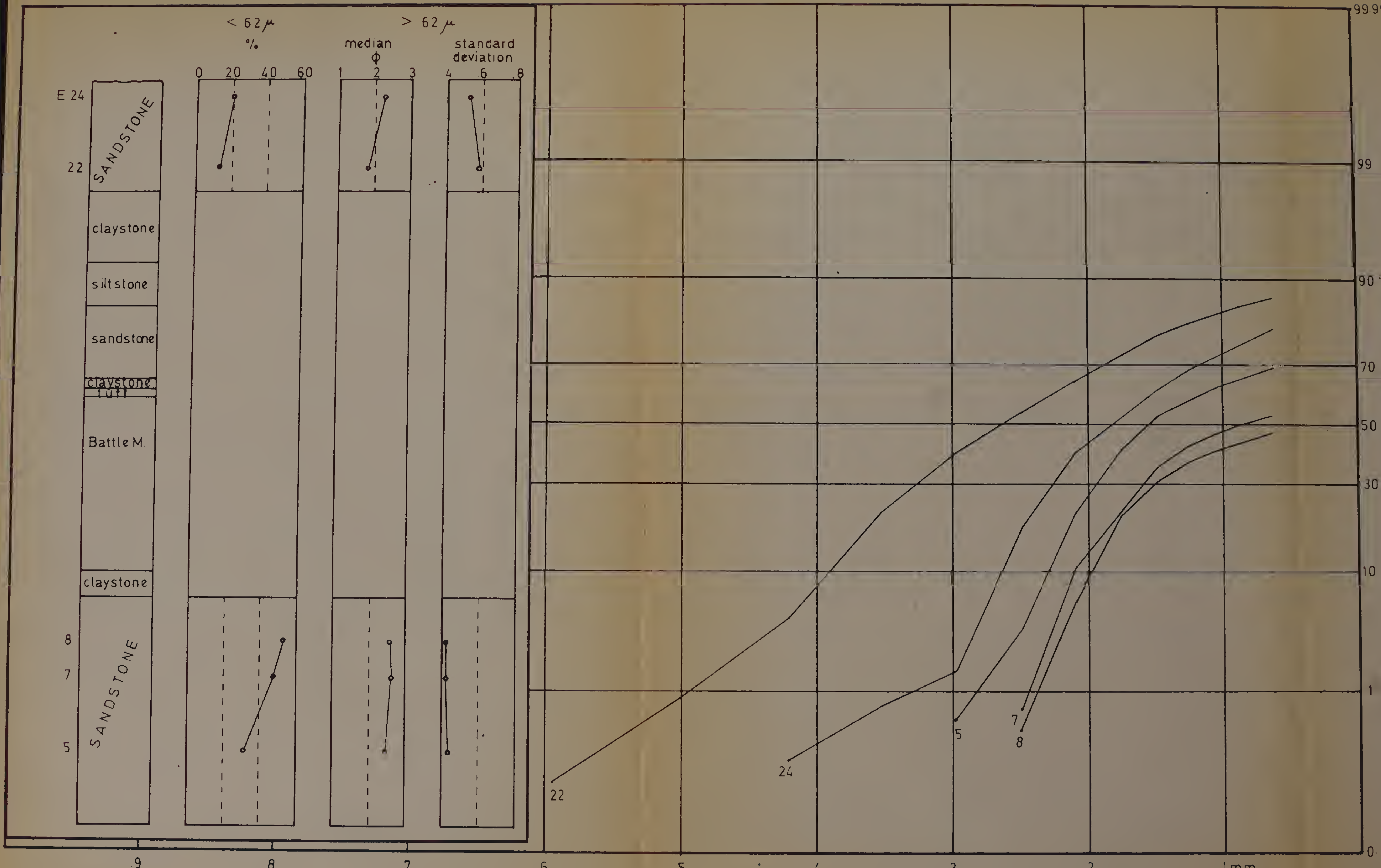


GRAPH II

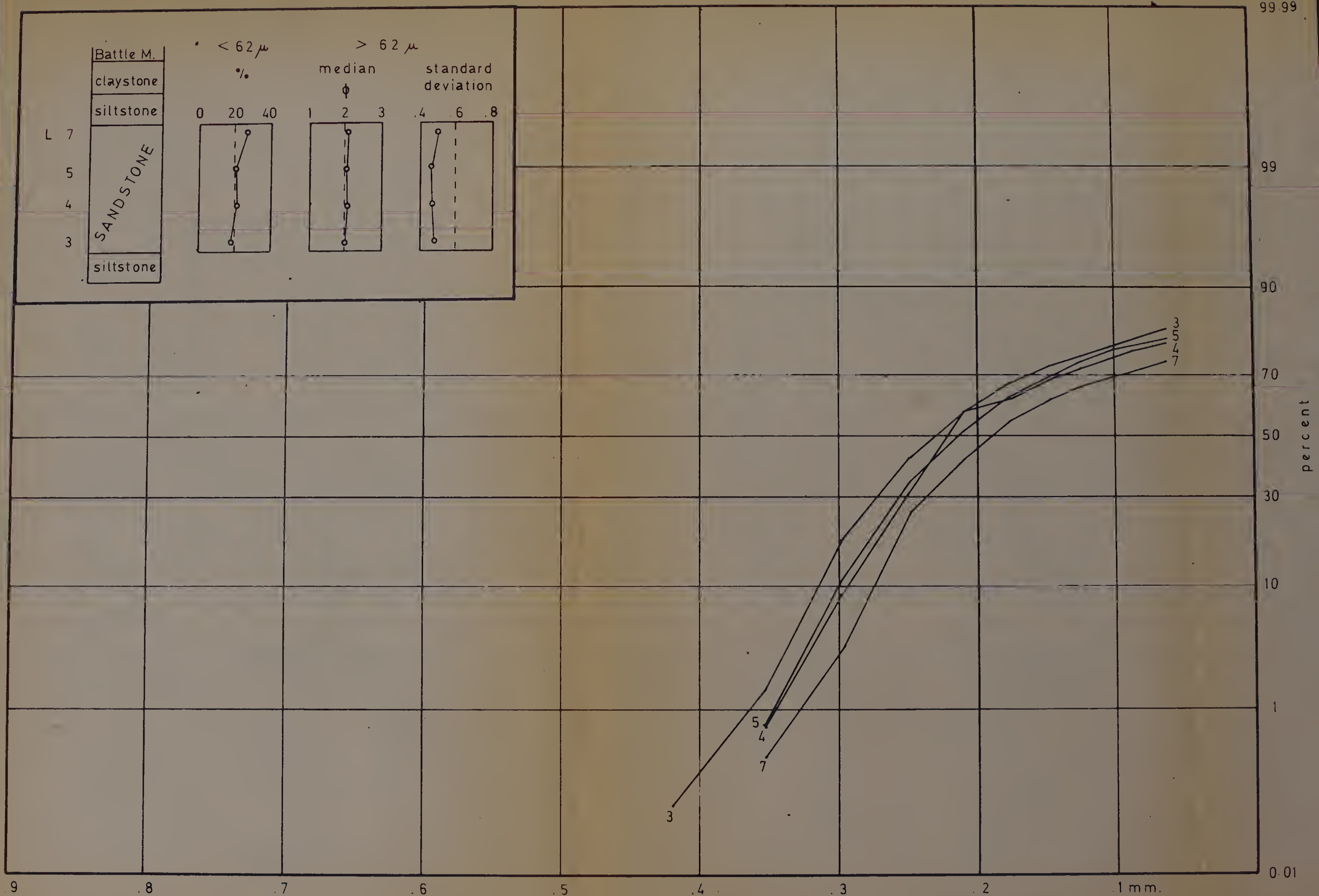


SECTION D
99.99
Battle Member
Shale
Sandstone
Shale
Sandstone
Shale
Siltstone
Shale
Sandstone
D 7
D 2
D 1
<62 μ
>62 μ
Median
ϕ
Standard deviation
0 20 40 60
1 2 3 4
.4 .6 .8
99
90
70
50
30
10
1
0.01
D 1
D 7
D 2
D 1
D 2
D 7
.4
.3
.2
.1 mm

GRAPH III section E

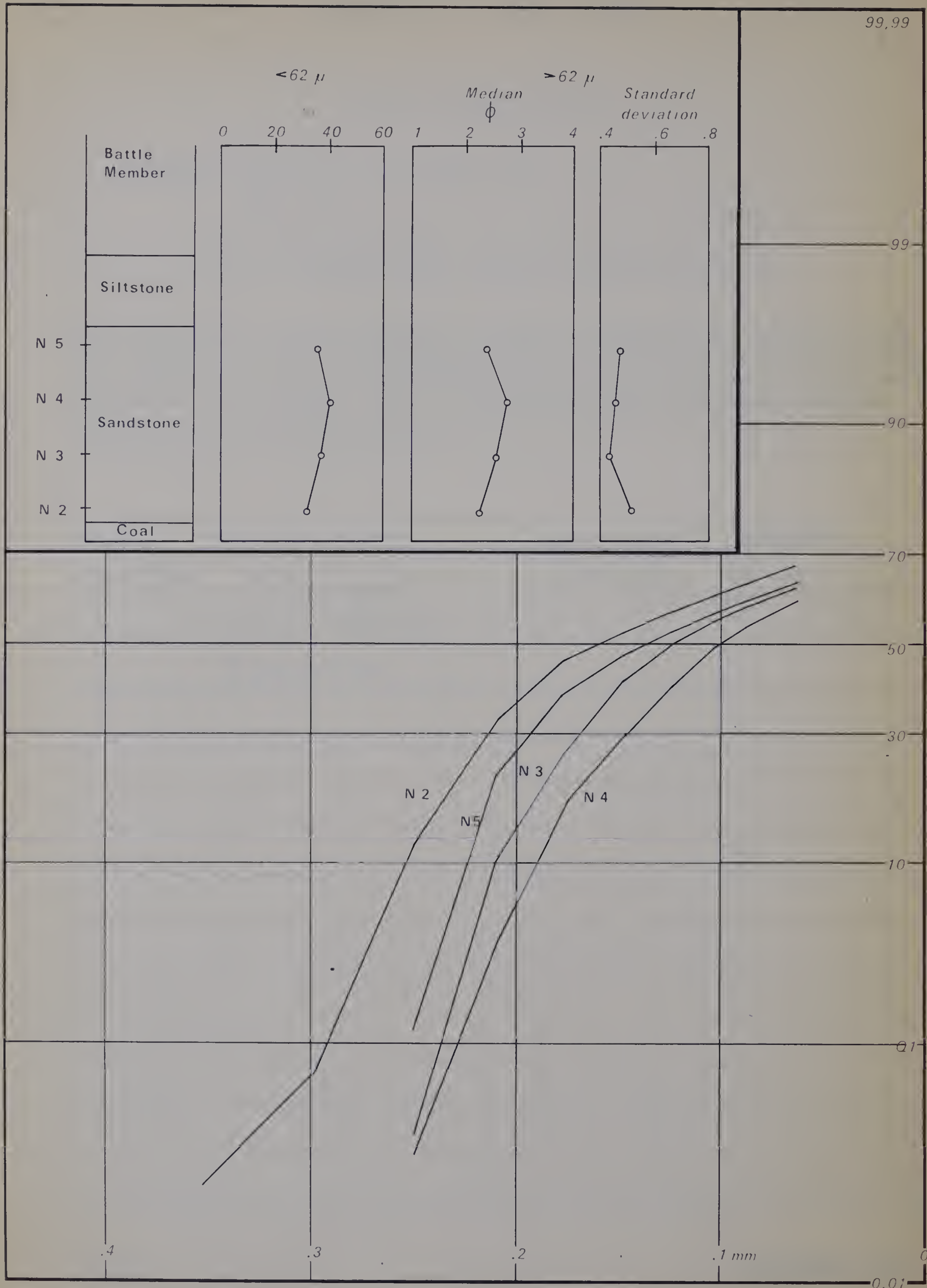


GRAPH IV section L



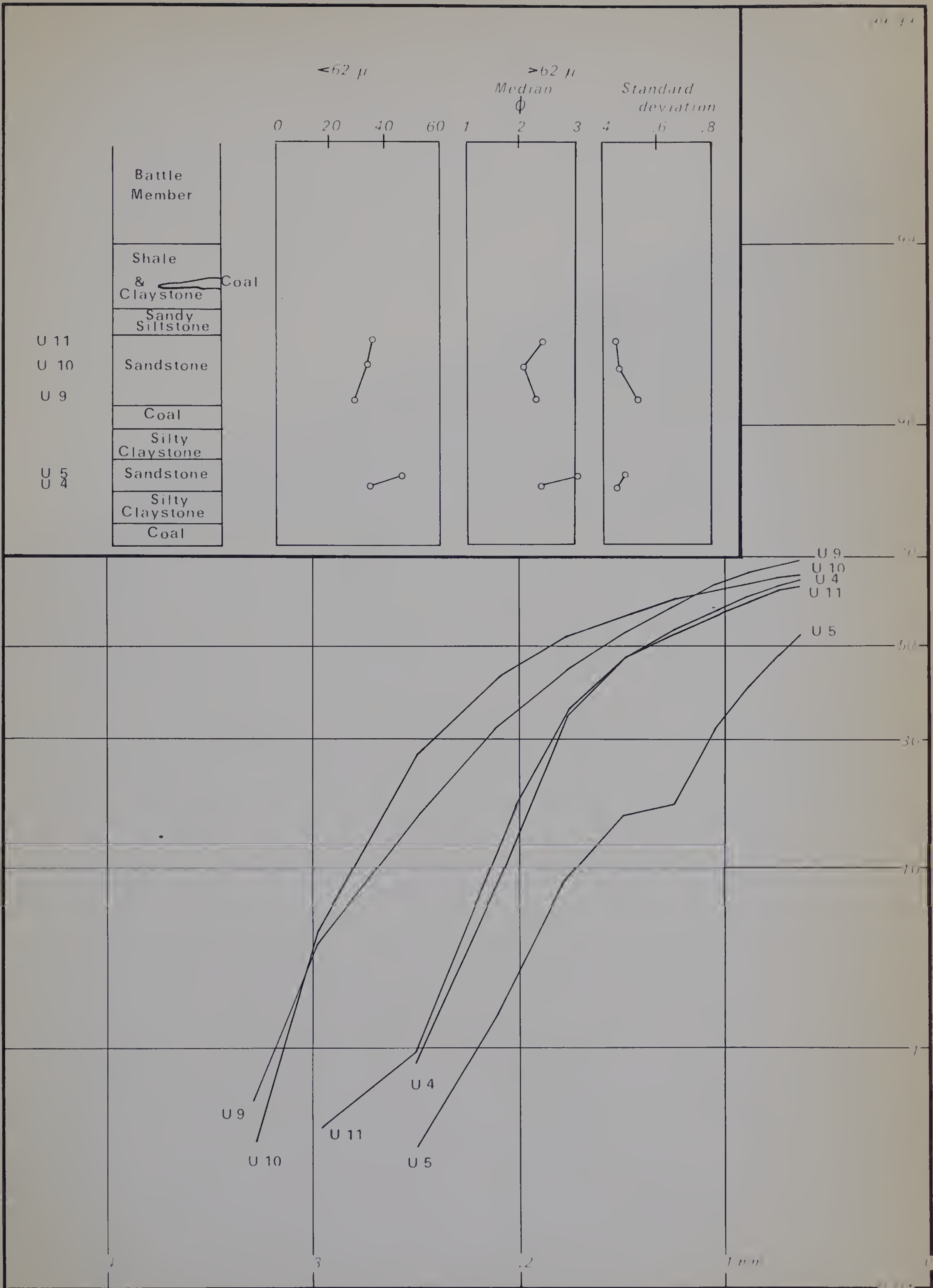
GRAPH V

SECTION N

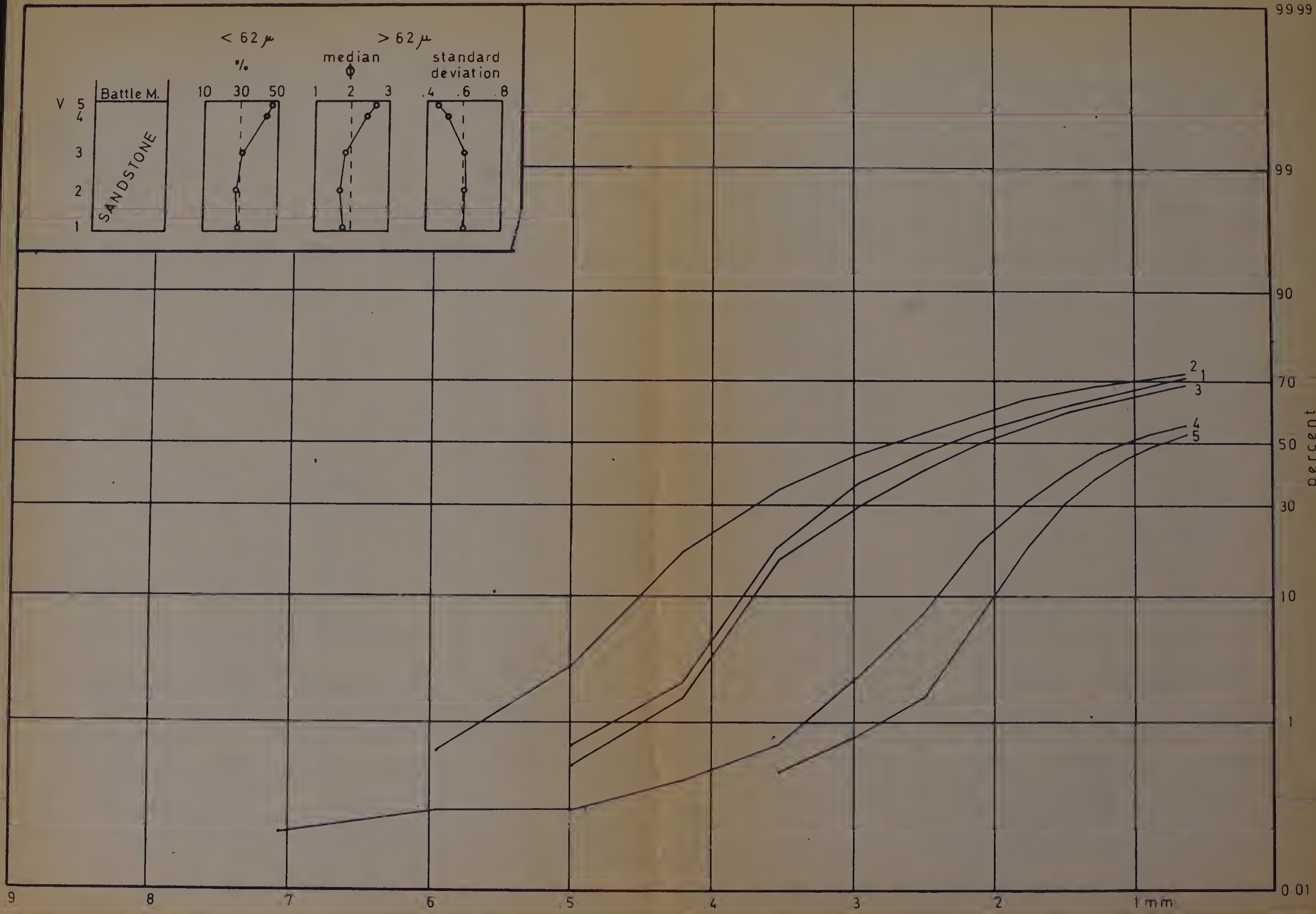


GRAPH VI

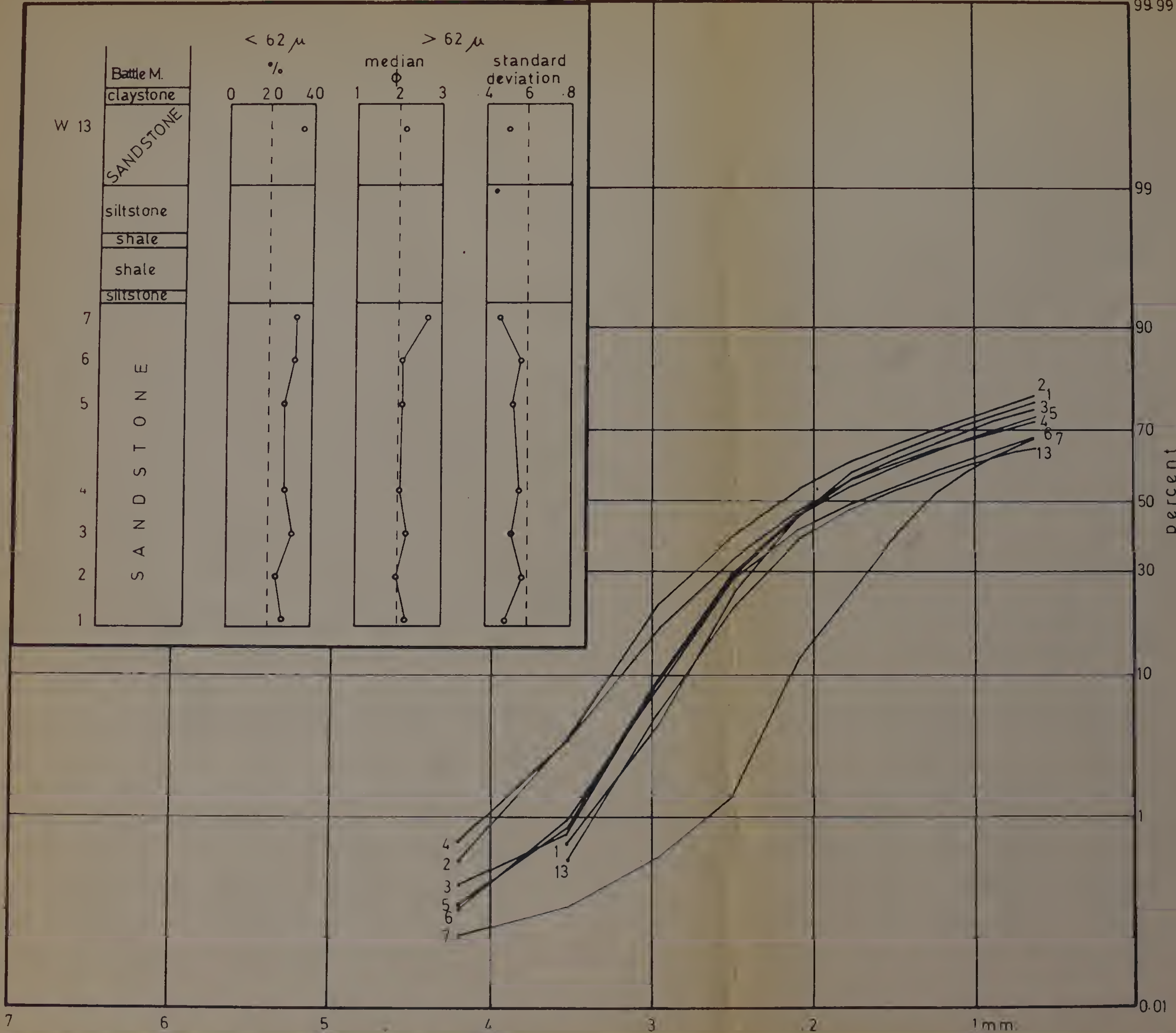
SECTION U



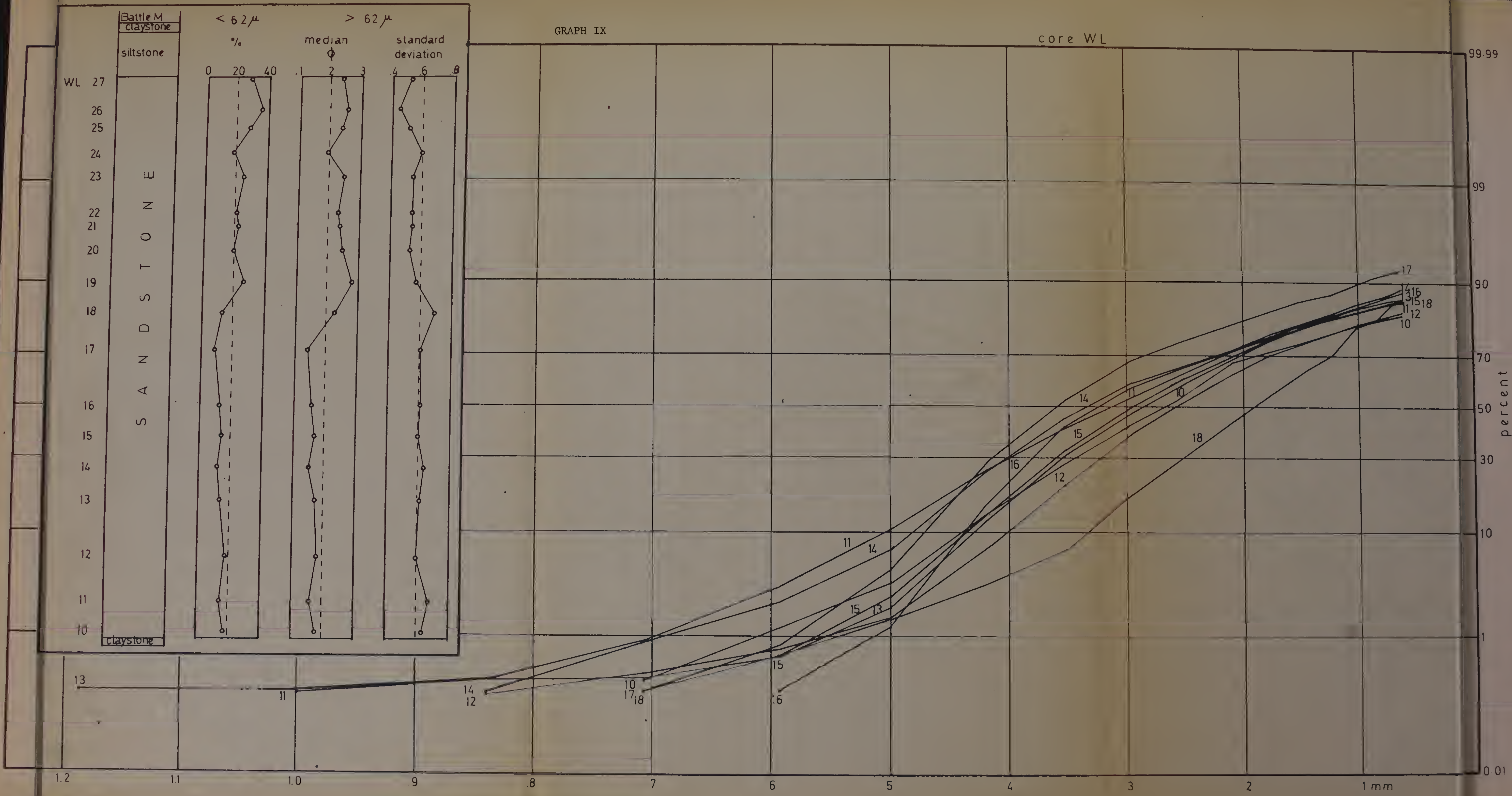
GRAPH VII section V



GRAPH VIII section W

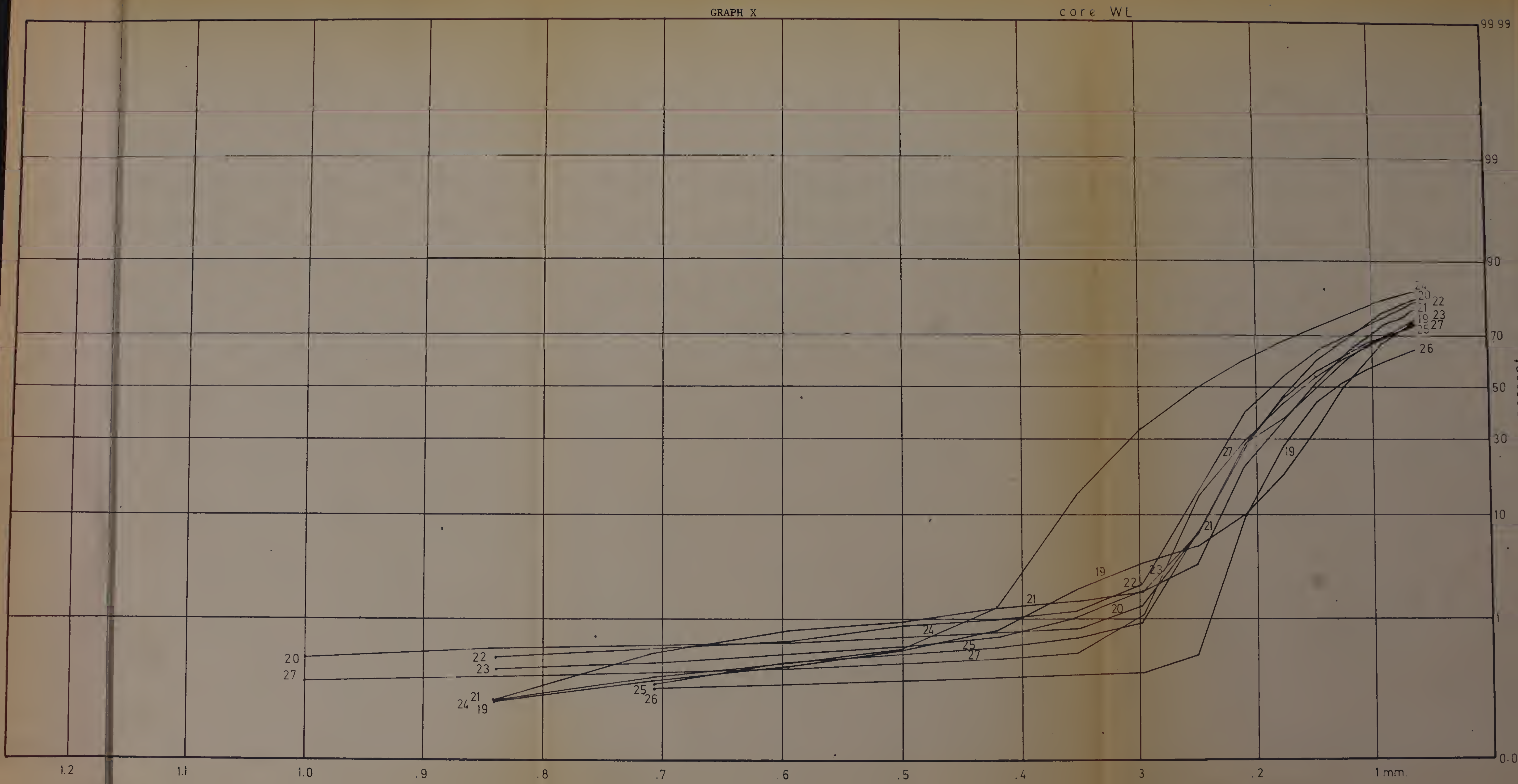


GRAPH IX



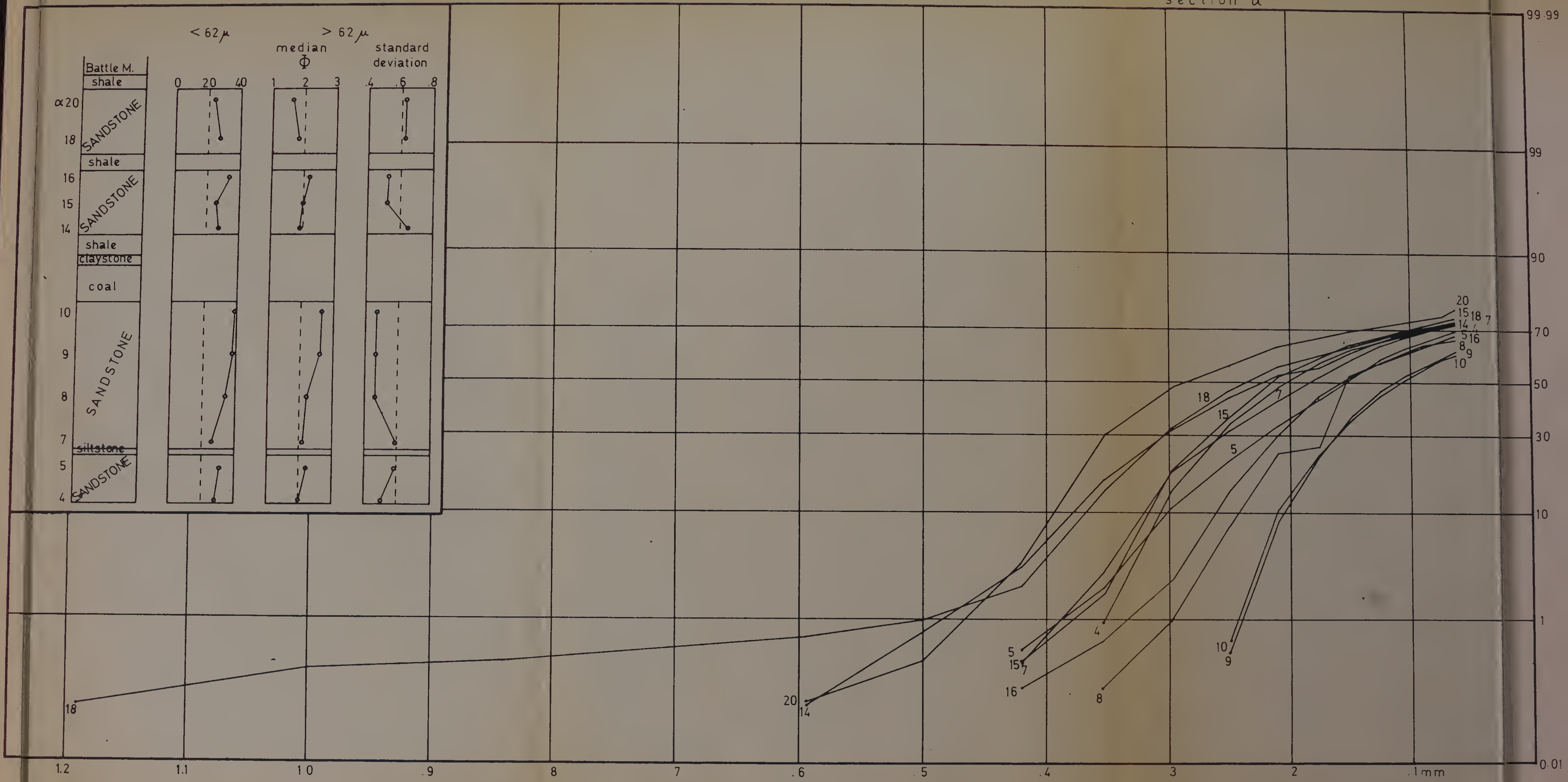
core WL
Battle M claystone
siltstone
SANDSTONE
claystone
< 62 μ %
> 62 μ median φ
standard deviation
WL 27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
99.99
99
90
70
50
30
10
1
0.01
percent
1.2
1.1
1.0
9
.8
7
6
5
4
3
2
1 mm

GRAPH X



core WL
99 99
99
90
70
50
30
10
1
0.01
percent
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
3
.2
1 mm.

GRAPH XI



section α
< 62 μ
> 62 μ
median
Φ
standard
deviation
Battle M.
shale
SANDSTONE
shale
SANDSTONE
shale
claystone
coal
SANDSTONE
siltstone
SANDSTONE
0 20 40
1 2 3
.4 .6 .8
α20
18
16
15
14
10
9
8
7
5
4
99.99
99
90
70
50
30
10
1
0.01
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1 mm